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RELATIONSHIP OF THE CLAY MINERALS HALLOYSITE AND ENDELLITE

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ABSTRACT

A study was made of the clay mineral halloysite, $Al_2Si_2O_5(OH)_4$, and the more highly hydrated related mineral, $Al_2Si_2O_5(OH)_4\cdot 2H_2O$, for which the name endellite is proposed. By means of chemical, electron-microscopic, *x*-ray diffraction, and petrographic methods, it was found that: (1) halloysite is formed by a partial dehydration of endellite; (2) halloysite has the same type of aluminum silicate layers as kaolinite, but the layers are usually superimposed in a less orderly manner in the former than in the latter; (3) endellite has a structure in which kaolinite-type layers alternate with single layers of water molecules; and (4) endellite may be formed by alteration of the constituents of a basic igneous rock, or its metamorphic equivalent.

The naming and identification of halloysite by Berthier in 1826[1] was based on type material from Angleur, Liege, Belgium, which closely resembles kaolinite in composition. Hofmann, Endell, and Wilm in 1934[2] described a more hydrous mineral from Djebal Deber, Libya, which apparently forms, by partial dehydration, the mineral called halloysite by Berthier. Hofmann, Endell, and Wilm, however, called their mineral halloysite and the original mineral from Belgium, metahalloysite. This shifting of names has caused considerable confusion which has been increased by Hendricks' suggestion[3] that the more hydrous material be called "hydrated halloysite." In an attempt to eliminate this confusion, and still preserve the original usage of the term halloysite, we suggest that the more hydrous mineral be called endellite in recognition of one of its discoverers.[4]

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[1] Berthier, P., *Ann. Chim. Phys.*, **32**, 332 (1826).

[2] Hofmann, U., Endell, K., and Wilm, D., *Angew. Chem.*, **47**, 539 (1934).

[3] Hendricks, S. B., *Am. Mineral.*, **23**, 295 (1938).

[4] The name hofmannite has previously been given to a hydrocarbon; Dana, *System of Mineralogy*, p. 1013.

The nature as well as the names of the minerals endellite and halloysite have been the subject of much controversy. It has generally been agreed, although without satisfactory evidence, that the formula of endellite is approximately $Al_2O_3 \cdot 2SiO_2 \cdot 4H_2O$. Three publications have appeared on the crystal structure of endellite, in each of which a different structure is proposed.[3,5,6]

The present study, which clarifies most of the questions which have been raised, was made possible only by the development of the electron microscope. The investigation was facilitated by the discovery of several new deposits of endellite, in two of which its mode of formation could be followed.

SOURCES OF MATERIALS

The halloysite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) samples studied were obtained from Dr. Clarence S. Ross, of the United States Geological Survey. These included specimens already described in a paper by Ross and Kerr[7] and designated by them as follows:

No. 2 from Angleur, Liege, Belgium (type material)
No. 3 from Lawrence County, Indiana ("indianaite")
No. 8 from Adams County, Ohio
No. 9 from Rankin County, Mississippi
No. 10 from Real County, Texas

Undescribed samples, also supplied by Dr. Ross, were from Iyo, Japan, Washoe County, Nevada, and Victor, Colorado. All of these specimens were porcelain-like in appearance with a conchoidal fracture. The least dimension of any one of the specimens was 1 centimeter and all probably occurred in much larger masses.

Four samples of endellite which had been kept under water were available for examination. Of these No. 21 was the type material from Djebal Deber, Libya, kindly sent by Professor Hofmann of the University of Rostock. Specimen No. 22 from the vicinity of Anamosa, Iowa, was obtained through the courtesy of Dr. P. G. Nutting of the United States Geological Survey. Some of the best material (No. 23) was obtained from the Dragon Consolidated mine, near Eureka, Utah. This apparently authigenic hydrothermal deposit has recently been described by Schroter and Campbell.[8] These endellite samples contained large areas of translu-

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[5] Mehmel, M., *Zeits. Krist.*, **90**, 35 (1935).

[6] Edelman, C. H., and Favejee, J. Ch. L., *Zeits. Krist.*, **102**, 417.

[7] Ross, C. S., and Kerr, P. F., *Prof. Papsr* **185–G,** *U. S. Geol. Survey*, Washington (1934).

[8] Schroter, G. A., and Campbell, I., *Am. Inst. Mining and Met. Engrs., Tech. Pub.* No. **1139–H,** 31 pp. (1940).

cent porcelain-like material with conchoidal fracture and, after drying at 100°C., closely resembled the halloysite specimens.

A somewhat more impure sample (No. 24) was collected in the vicinity of Rockdale, near Baltimore, Md., where endellite had been formed by alteration of plagioclase feldspar in an epidote amphibolite. Endellite persisted in the "C" horizon of the associated soil.

Electron Microscope Photographs

Electron microscope photographs of halloysite and endellite were made in the laboratories of the National Bureau of Standards, using the apparatus manufactured by the Radio Corporation of America. The initial magnifications were usually about 10,000 diameters, but a few photographs were taken at about 18,000 diameters.

The specimens examined were first ground for a few minutes in an agate mortar and then dispersed in water. In some instances it was necessary to use a few drops of dilute ammonium hydroxide as a dispersing agent. After allowing the coarser material to settle, the suspended sample was diluted to such a concentration that a drop would give a mount of the desired density when applied to a thin collodion membrane. The membrane, which had been prepared by the spreading of a dilute collodion solution on water, was supported on an electroplated 200-mesh gauze. After drying at room temperature, the mounted sample was introduced into the electron microscope. Since the microscope is necessarily evacuated, the endellite samples were probably completely changed to halloysite, but this should not have interfered with observations on the morphology of individual particles.

Although the typical lath-shaped form of the halloysite fragments, well shown in Figs. 1, 2, and 3, has previously been observed in electron microscope images by Shaw and Humbert,[9] the halloysite from Lawrence County, Indiana (Fig. 1, 1) exhibits geometrical arrangements of laths, serrations on the lath edges, and indentations on the lath ends not hitherto noted. Thus, the portion of the object indicated by *A* in Fig. 1, 1, appears to be formed from a number of related fragments between which an angle of about 60° frequently occurs. This is perhaps more clearly shown in Fig. 4 where the oriented portion of the photograph is sketched. This arrangement was noted in other electron micrographs of the material. It is probable that the related fragments are only part of a much larger system that had been degraded since the formation of the mineral.

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[9] Shaw, B. T., and Humbert, R. P., *Proc. Soil Sci. Soc. Am.*, **6**, 146–149 (1941).

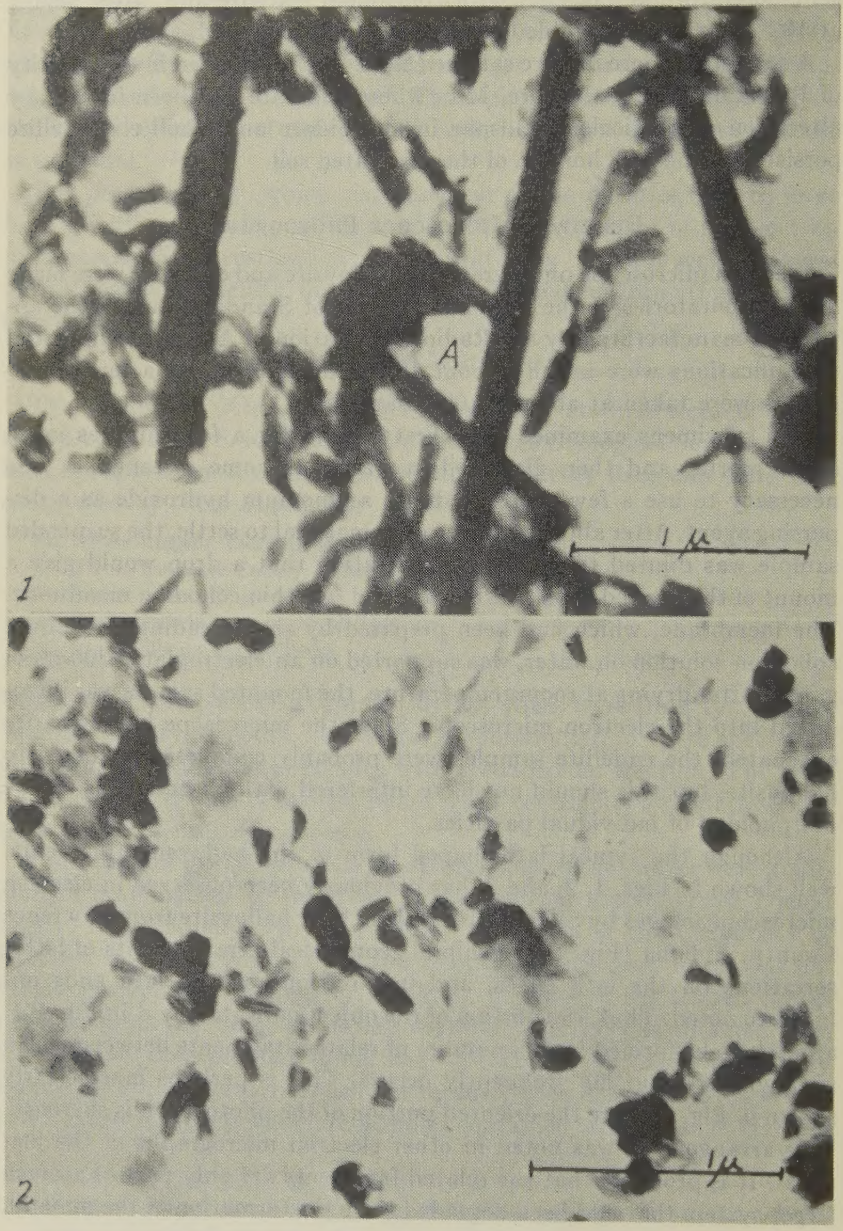

FIG. 1. (1) Halloysite ("indianaite"), Lawrence County, Indiana.
(2) Endellite, Rockdale, Maryland.

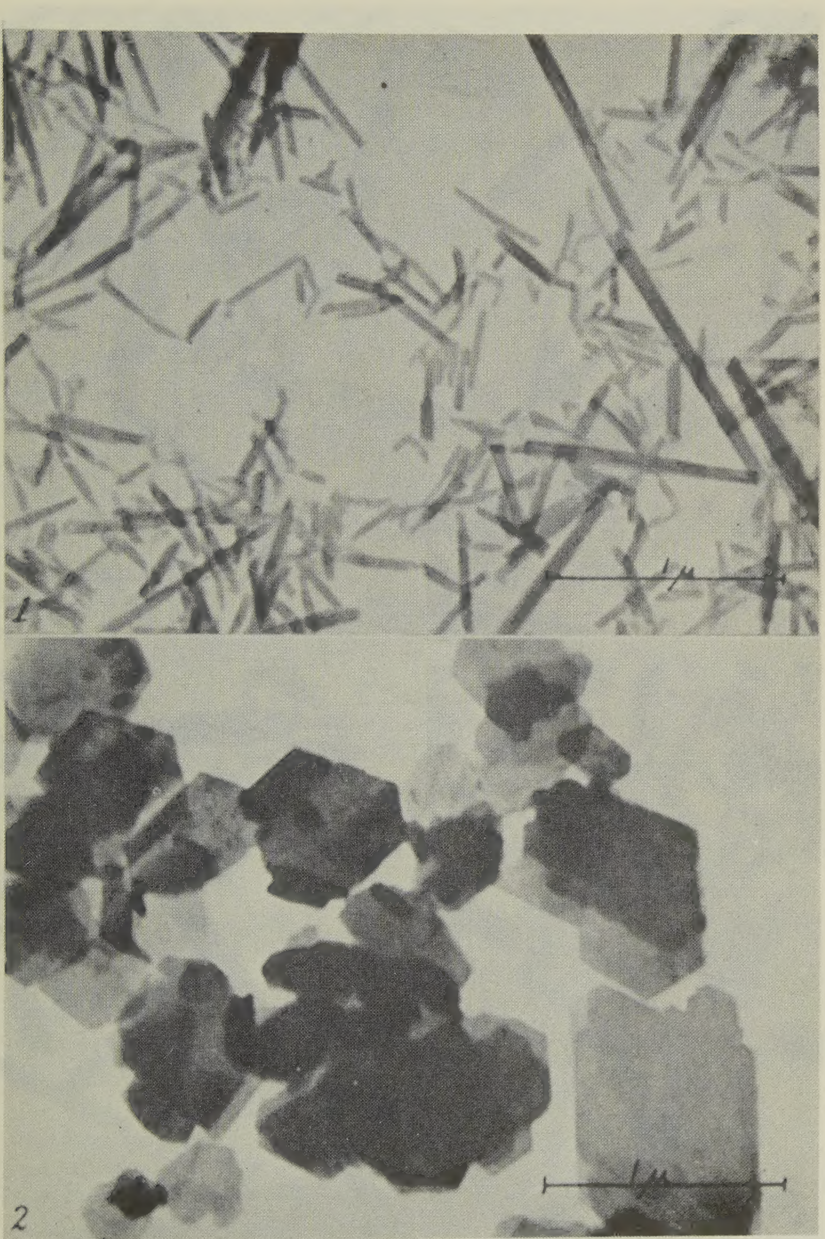

FIG. 2. (1) Endellite, Anamosa, Iowa. (2) Kaolinite, Georgia.

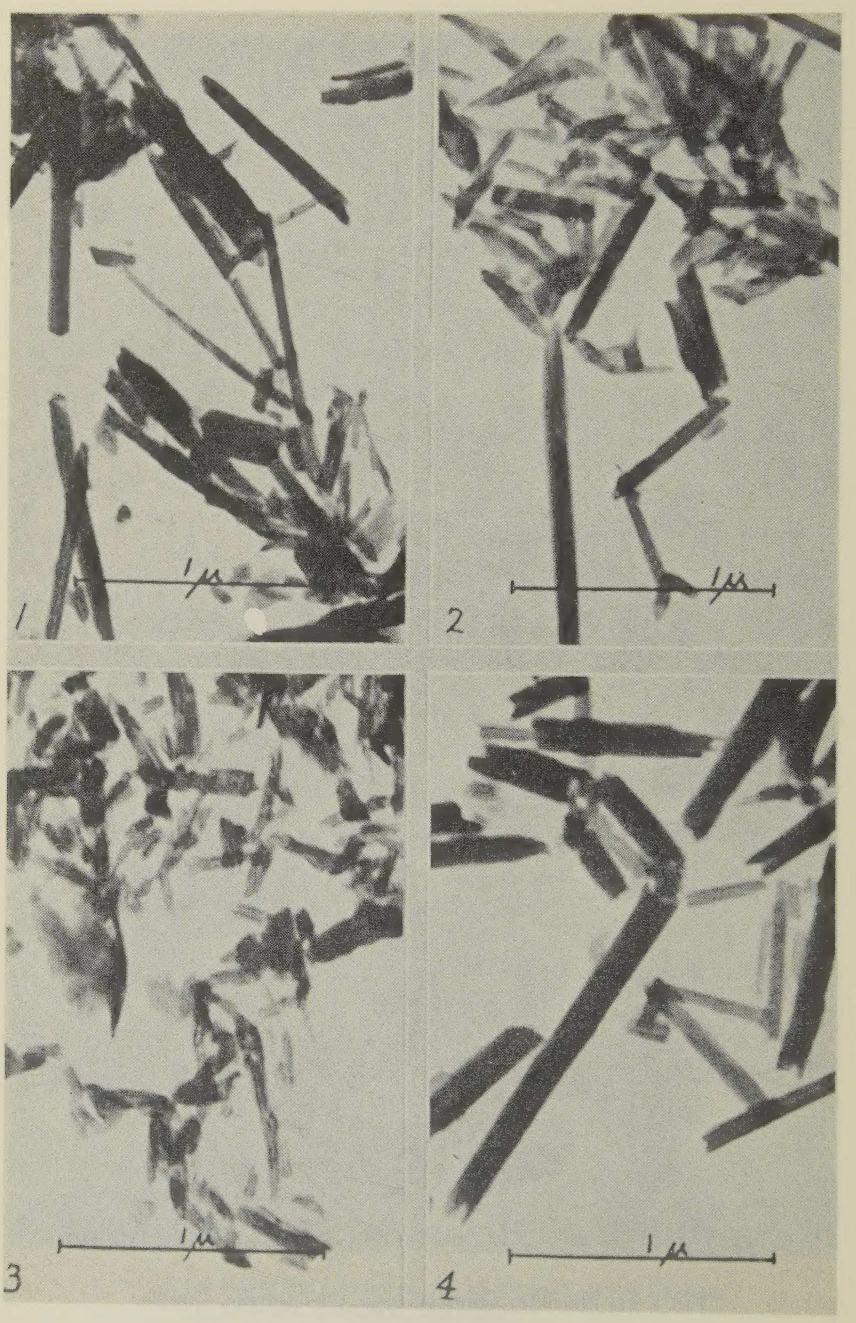

Fig. 3. (1) Halloysite, Iyo, Japan.
(2) Endellite, Djebal Deber, Libya.
(3) Halloysite, Liege, Belgium.
(4) Halloysite, Real County, Texas.

The endellite specimen from the vicinity of Rockdale, Md., was known to contain a mixture of several clay minerals. Endellite relic laths are numerous in the photograph reproduced as Fig. 1, 2, but some hexagonal plates may also be observed. None of the endellite specimens gave results essentially different from those obtained for halloysite. Authentic specimens of kaolinite usually contain hexagonal plates and none has been found to have the lath-like fragments of endellite and halloysite. A typical kaolinite photograph is reproduced in Fig. 2, 2.

Many of the endellite and halloysite fragments display a true or apparent longitudinal division as shown in Fig. 3. Although some of the fragments do not appear to be divided, their indented or notched ends may be indicative of such division. Fragments of endellite or halloysite from any particular specimen have a tendency to be similar in dimensions. This feature, observed repeatedly, is probably a characteristic of the material.

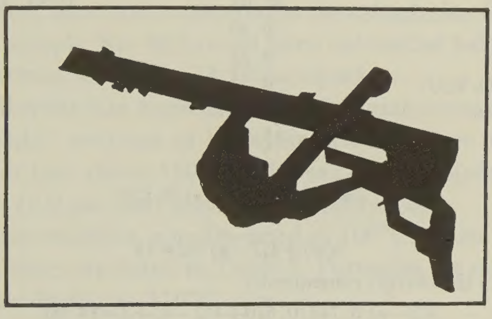

FIG. 4. A tracing of a portion of Fig. 1 (1) showing related fragments of halloysite.

COMPOSITION OF HALLOYSITE AND DEHYDRATED ENDELLITE

Chemical formulas for halloysite and dehydrated endellite which express the relationship between ions in tetrahedral and octahedral coordination can be developed after certain assumptions are made. These assumptions are:

1. There is a fixed ratio, 5:4, of oxygen to hydroxyl ions.
2. The ratio of ions in tetrahedral coordination to oxygen ions is 2:5.
3. All silicon ions are in tetrahedral coordination.
4. Possible isomorphous substitution of Mg^{++}, Fe^{+++}, Na^{+} or Li^{+} for Al^{+++} is neglected.

The formula then is of the type

$$Al_{m-n}(Al_nSi_{2-n})O_5(OH)_4X_a$$

in which m represents the total Al^{+++} present, n the number of ions to be added to Si^{++++} to bring the number of cations in tetrahedral coordination to 2, and X_a represents the replaceable base. The value of a in the expression X_a is 0.02, corresponding to the usual exchange capacity of the kaolin minerals, i.e., about 0.08 milliequivalent per gram.

To illustrate the calculation of the formula, the analysis given by Ross and Kerr[7] of their sample No. 3 may be used. The analysis and the corresponding atomic equivalents of Si^{++++} and Al^{+++} are:

	Per cent	*Atomic equiv.*
SiO_2	40.26	Si^{++++} 0.670
Al_2O_3	37.95	Al^{+++} 0.744
Fe_2O_3	0.30	
CaO	0.22	
Na_2O, K_2O	0.74	
$-H_2O$	4.45	
H_2O	15.94	

Since

$$(m)/0.744=(2-y)/0.670$$

and

$$3(m)+4(2-n)+a=14$$

in order to balance the charge; consequently

$$3(2-n)\ 0.744/0.670+4(2-n)+a=14.00.$$

The formula, therefore, is $Al_{2.024}(Al_{.092}Si_{1.908})O_5(OH)_4X_{.02}$, which, considering the limits of analytical accuracy and the validity of assumptions concerning base exchange and isomorphous substitution, may be simplified to $Al_{2.02}(Al_{.09}Si_{1.91})O_5(OH)_4X_{.02}$. Relative amounts of Al^{+++} in tetrahedral and octahedral coordination are not significantly affected by the above assumptions. The formulas for nine of the 13 halloysite specimens, the analyses of which are published by Ross and Kerr,[7] are given in Table 1.

TABLE 1. FORMULAS OF HALLOYSITE SPECIMENS

Ross-Kerr no.	Formula
3	$Al_{2.02}(Al_{.09}Si_{1.91})O_5(OH)_4X_{.02}$
4	$Al_{2.00}(Al_{.02}Si_{1.98})O_5(OH)_4X_{.02}$
5	$Al_{1.99}(\quad Si_{2.00})O_5(OH)_4X_{.02}$
6	$Al_{2.01}(Al_{.04}Si_{1.96})O_5(OH)_4X_{.02}$
7	$Al_{2.00}(Al_{.03}Si_{1.97})O_5(OH)_4X_{.02}$
8	$Al_{2.02}(Al_{.08}Si_{1.92})O_5(OH)_4X_{.02}$
9	$Al_{2.00}(Al_{.02}Si_{1.98})O_5(OH)_4X_{.02}$
12	$Al_{2.01}(Al_{.04}Si_{1.96})O_5(OH)_4X_{.02}$
13	$Al_{2.02}(Al_{.08}Si_{1.92})O_5(OH)_4X_{.02}$

The foregoing method does not give a satisfactory formula for sample 2, the type material from Liege, Belgium, since the $SiO_2:Al_2O_3$ ratio of this material is 2.06:1.00 and, therefore, is in excess of the 2.00:1.00 limitation imposed by the formula. This high ratio may be the result of a slight amount of silica as an impurity, either as a separate phase or as an anauxite type material. Ross and Kerr's sample 11, from Newton County, Arkansas, probably contains diaspore or gibbsite as an impurity, since the water lost above 110° is relatively high, the $SiO_2:Al_2O_3$ ratio is low and other samples from that locality contain such impurities. The amounts of alkali in the samples, which were usually low and in some cases not reported, were not considered in the calculation of the formulas. The formula of sample No. 10 has not been calculated because of the unusually high content of alkalies (1.19 per cent).

Although halloysite has approximately the same formula as kaolinite, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$,[7] analyses of halloysite always show more than 14.4 per cent of water lost above 110°C., whereas pure kaolinte samples have very nearly the 13.9 per cent required by the formula.

Analyses of five endellite samples dried at 100°C., from the four localities described above, are listed in Table 2. Formulas for samples Nos. 21, 22, and 23, after drying at 110°C., are:

(21) $Al_{2.02}(Al_{.03}Si_{1.97})O_5(OH)_4X_{.03}$
(22) $Al_{2.01}(Al_{.05}Si_{1.95})O_5(OH)_4X_{.02}$
(23) $Al_{2.02}(Al_{.08}Si_{1.92})O_5(OH)_4X_{.00}$

Sample No. 22*a*, the fine fraction of the Anamosa, Iowa, material, was shown by differential thermal analysis to contain about 20 per cent of gibbsite. The material from Rockdale, Maryland, sample 24, contains both kaolinite and the iron-bearing clay mineral, nontronite, as shown by examination with a petrographic microscope.

TABLE 2. ANALYSES OF ENDELLITE SAMPLES DRIED AT 110°C.

	21	22	22a	23	24
SiO_2	45.20	44.51	35.26	44.35	45.46
Al_2O_3	38.96	39.90	45.24	40.35	36.69
Fe_2O_3	0.21	0.21	0.44	0.21	3.51
CaO	0.00	0.00	0.00	0.00	0.00
MgO	0.08	0.05	0.34	0.04	0.32
Ignition loss	15.35	15.44	19.46	15.54	14.34
Total	99.80	100.11	100.74	100.49	100.32

21 Djebal, Deber, Libya.
22 Anamosa, Iowa, translucent piece.
22a Anamosa, Iowa, fraction less than 2 microns in size.
23 Eureka, Utah.
24 Rockdale, Md., fraction less than 2 microns in size.

The base exchange capacities of samples Nos. 22, 23, and 24 were determined by first saturating the clay at *pH* 7.0 with Ba^{++}, from 0.2 N. $BaCl_2$ which was then displaced by treatment with NH_4Cl. The displaced Ba^{++} was determined gravimetrically as the sulfate. Observed capacities are: No. 22, 0.08; No. 23, 0.01; No. 24, 0.21 m.e. per gram. The high exchange capacity of the material from Rockdale, Md., No. 24, was due to the nontronite in it.

These several samples of dehydrated endellite have very nearly the same composition as found for halloysite by Ross and Kerr.

IDENTIFICATION OF ENDELLITE BY *X*-RAY DIFFRACTION, WATER CONTENTS, REFRACTIVE INDICES, AND DENSITIES

Mehmel[5] gives *x*-ray powder diffraction data for halloysite and endellite. Endellite has an intense reflection with a spacing of 10.1Å, while the greatest spacing of halloysite is 7.2Å. Otherwise the diffraction patterns are closely similar. Hofmann, Endell, and Wilm[2] first showed, and others have verified their observations, that drying endellite even at room temperatures causes it to give the diffraction pattern of halloysite. Efforts to obtain endellite by hydrating halloysite have not been successful.

The four endellite specimens examined in this work gave mixed diffraction patterns of endellite and halloysite. All of the samples showed varying water contents, depending upon the humidity. Typical results, obtained from the Eureka, Utah, sample (No. 23) that had been ground to pass a 325-mesh screen, are reproduced in Fig. 5. The sample was brought to equilibrium at 30°C., first at 75 per cent and subsequently at lower relative humidities. The results of duplicate experiments are shown by circles in Fig. 5. After equilibration at the lower relative humidities, the samples were again brought to equilibrium at 75 per cent relative humidity. The amounts by which they failed to regain their initial weights are indicated by circles with attached arrows.

The endellite samples examined are partially reversible in their hydration. When samples of endellite (Eureka, Utah) were dried at 300°C. and again brought to equilibrium at 30°C. and 75 per cent relative humidity, they readsorbed about 50 per cent of the water lost, but the intense diffraction line at 10.1Å, characteristic of endellite, did not reappear. It would seem that this water taken up by the dehydrated endellite is merely adsorbed, as also is a part of the water in the original samples.

Somewhat different results for the dehydration characteristics of endellite were obtained by Hofmann, Endell, and Wilm[2] and by Correns and Mehmel.[10] The endellite used by Hofmann, Endell, and Wilm probably contains gibbsite as an impurity, as indicated by the weight loss of 19 per cent at temperatures above 200°C., while that of Correns and Mehmel contained less admixed halloysite (their metahalloysite) than did the material from Eureka, Utah.

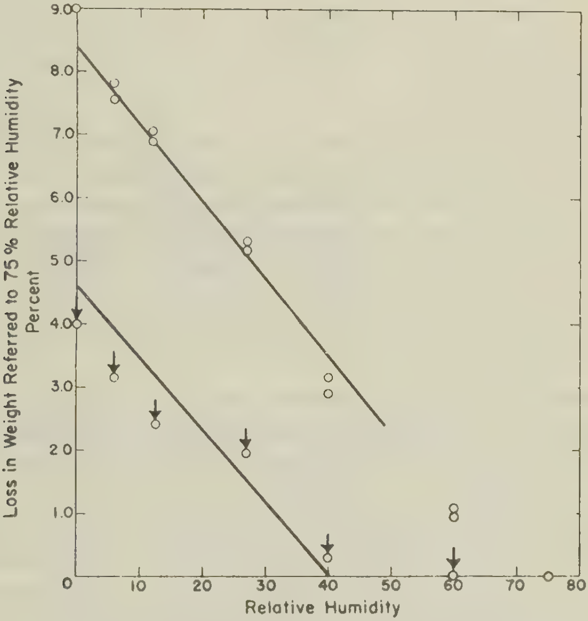

FIG. 5. Effect of relative humidity at 30°C. upon loss of water from partially dehydrated endellite.

Although Correns and Mehmel[10] indicate that the refractive index of endellite determined by use of the immersion method depends upon the immersion liquid, careful measurements by one of the present authors (G. T. Faust), using several liquids, failed to show this effect (Table 3). When care was used to insure penetration of the specimen by the liquid, no change was noted in the refractive index either with the liquid used or with the length of time in contact with the liquid, after displacement of the surface water in the first few seconds. If the surface film of water were not completely removed, as in case of a totally immiscible liquid, values too low would be obtained.

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[10] Correns, C. W., and Mehmel, M., *Zeits. Krist.*, **94,** 337 (1936).

TABLE 3. APPARENT REFRACTIVE INDICES OF ENDELLITE SPECIMENS FOR Na_D LIGHT

	(a) Rohrbach's solution in glycerin	(b) Glycerine and quinoline	(c) Mineral oil and monochloronaphthalene	Dehydrated endellite or halloysite in (c)
21	1.543	1.543	1.540 1.545	1.556
22	1.543	1.541		
23		1.542		1.551
24	1.551	1.552		1.556

The values of the refractive indices of endellite listed by Correns and Mehmel[10] vary between 1.528 and 1.550, which includes the range shown in Table 3. While Correns and Mehmel consider these values to be those of endellite, they probably are values for mixtures of endellite and halloysite. The true value, as shown later, is probably 1.490 ± .005. Using this figure for pure endellite, none of the specimens so far measured contains more than 50 per cent of endellite, the remainder being its dehydration product, halloysite.

There appears to be no unequivocal method of determining directly the water content of endellite because no samples unmixed with halloysite seem to be available. An indirect method was adopted, however, based on the assumptions that the halloysite in the samples was derived from endellite, that no volume change in the specimen accompanied the change from endellite to halloysite, and that the submicroscopic pores produced by the change are completely refillable with water. Dense, coherent, and porcelain-like specimens were chosen as most nearly fulfilling these conditions and density determinations were made on such samples by determining their weights after drying at 110°, the weights after the pores were filled with water, and the water displacement of the wet samples. The percentages of water lost by wet specimens when dried at 110°C. as shown in Table 4, column 4, agree within the limits of experimental error with the water loss accompanying the change of $Al_2Si_2O_5(OH)_4 \cdot 2H_2O$ to $Al_2Si_2O_5(OH)_4$. The results provide evidence that the composition of endellite is $Al_2Si_2O_5(OH)_4 \cdot 2H_2O$.

Specimens with lower densities when the pores are water-filled, such as that from Washoe County, Nevada, with density of 2.03 and that from Adams County, Ohio, with density of 2.02, are less coherent and porcelain-like than those listed in the table, indicating that the original samples of endellite were not free from voids.

TABLE 4. DENSITIES FOR HALLOYSITE AND DEHYDRATED ENDELLITE SPECIMENS

Source of specimen	Density		Per cent of water in wet specimen lost by drying at 110°C.
	Specimen with pores filled with water	Specimen dried at 110°C.	
Eureka, Utah	2.11; 2.13	2.58	13.7
Iyo, Japan	2.17	2.60	12.4
Lawrence County, Indiana	2.16	2.59	12.5
Calculated values	2.12[1]	2.61[3]	12.24[2]

[1] Calculated for $Al_2Si_2O_5(OH)_4 \cdot 2H_2O$ with

$$a_0=5.1Å,\ b_0=8.9Å,\ c_0=10.25Å,\ \beta=100°12'.$$

[2] Calculated for loss of $2H_2O$ from $Al_2Si_2O_5(OH)_4 \cdot 2H_2O$.

[3] Calculated for $Al_2Si_2O_5(OH)_4$ (halloysite) with

$$a_0=5.1Å,\ b_0=8.9Å,\ c_0=7.2Å,\ \beta=100°12'.$$

CRYSTAL STRUCTURE OF ENDELLITE AND HALLOYSITE

The atomic arrangement in endellite was first studied by Mehmel,[5] who suggested that it is formed of alternate $Al_2(OH)_6$ and $Si_2O_3(OH)_2$ layers. Hendricks[3] showed that this type of structure does not account for the intensities of the (001) reflections and proposed in its place one in which $Al_2Si_2O_5(OH)_4$ layers, similar to those of kaolinite, are interleaved with layers of water molecules. For the latter structure the computed and observed intensities are in agreement.

An alternative structure for endellite was proposed by Edelman and Favejee,[6] who considered it made up of $Al_2Si_2O_4(OH)_6$ layers with possibly some water adsorbed between layers. There are a number of objections to the structure. It does not explain the intensities of the (001) reflections and, in addition, calculations show that the second order should have an appreciable intensity. Actually, this reflection, which should appear with a spacing of 5.05Å, is not present. This proposed structure, moreover, leads to a composition of $Al_2Si_2O_4(OH)_6 \cdot XH_2O$, which is not in agreement with the probable water content as adduced in the last section. Perhaps worst of all, it is not a structure that by loss of water could form halloysite with a separation of silicate layers near 7.2Å.

Part of the confusion concerning the structure of these minerals arises from the fact that the powder patterns of kaolinite and halloysite differ only in the character and strength of the reflections from lattice planes oblique to the base. They are always diffuse and weak in halloysite, whereas the corresponding reflections in kaolinite are usually sharp.[11] These diffuse reflections are evidence of great disorder in the stacking of the $Al_2Si_2O_5(OH)_4$ layers. There appears to be no essential objection to the structure of endellite originally proposed by Hendricks[3] and to the conclusions that halloysite is a kaolin-type mineral and that it usually has considerable disorder in the stacking of the silicate layers.

The refractive index calculated for $Al_4Si_4O_{10}(OH)_8 \cdot 4H_2O$, assuming a unit structure having $a_0 = 5.1$ Å, $b_0 = 8.9$ Å, $c_0 = 10.25$ Å, $\beta = 100°12'$, with $Al_4Si_4O_{10}(OH)_8$ having the molecular refractivity found for kaolinite and that of water, is $1.490 \pm .005$.

GENESIS OF ENDELLITE AND HALLOYSITE

Evidence that halloysite is formed from endellite is:

1. Samples of halloysite and endellite subjected only to changes brought about by pressure and temperature conditions within the electron microscope have identical geometrical arrangements, crystal habits, and shapes.
2. These habits and shapes are quite different from those of kaolinite, although the latter is almost identical with halloysite in *x*-ray structure.
3. Many porcelain-like specimens of endellite-halloysite when their pores are filled with water have the density calculated for endellite ($Al_2Si_2O_3(OH)_4 \cdot 2H_2O$).
4. The content of the water lost above 110° is always greater in halloysite than in kaolinite.[12]

Ross and Kerr's[7] discussion of the origin of halloysite thus really refers to endellite. To this can be added the surmise that endellite is formed only in the presence of liquid water or an almost saturated vapor.

The absence of preferred orientation in a number of the halloysite fragments is shown by the nature of the *x*-ray diffraction photographs made on a Weissenberg goniometer, and also by the lack or very low order of birefringence observed in the polarizing microscope. Thus, while the large original pieces probably did not contain voids, they were polycrystalline on a microscopic or possibly sub-microscopic scale. The connected remnants of the crystal shown in Fig. 1, and sketched in Fig. 4, indicate that the original platelike crystal of endellite was at least 2 microns in greatest dimensions.

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[11] Some samples of kaolinite also give diffuse reflections from these planes (private communication from H. F. Carl of the United States Bureau of Mines).

[12] This additional water is probably adsorbed on the very fine material left by dehydration of the endellite since measurements of surface area by the nitrogen adsorption method made by R. A. Nelson on dehydrated endellite from Eureka, Utah, gave 90 sq. meters per gram, which is greater than that of any kaolinite yet measured.

The genesis of endellite is well illustrated in the occurrence near Rockdale in Baltimore County, Maryland. Here the rocks consist of gabbros which have undergone varying degrees of metamorphism. Endellite occurs as segregations in the zone of weathered rock, or as small pockets disseminated in the weathered rock itself. Columnar sections illustrating the occurrence are given in Fig. 6.

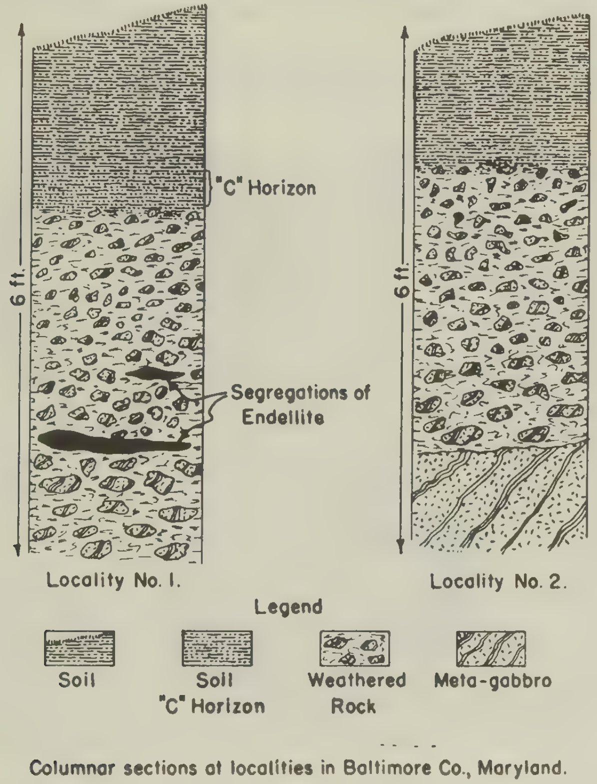

FIG. 6. Columnar sections illustrating occurrence of endellite near Rockdale, Baltimore County, Maryland.

Locality No. 1. The specimen was taken from a trench, along the west side of the road from Rockdale to Scotts Level, at a point 250 feet south of the intersection of the road and the stream. The site is on the wooded flank of a hill along which a trench about 6 feet deep had been dug for some distance up the hill. The rock from which the endellite was derived is an epidote amphibolite. This rock has a porphyroblastic texture, a fine to medium grain size, and a blackish green-gray color. The principal constituent is hornblende with a well developed prismatic cleavage and strong pleochroism (Z = deep bluish green, Y = Yellowish green, X = pale greenish yellow). Some of the crystals possess schiller inclusions, a relic of the former hypersthene. It is biaxial negative, with 2V almost 90°, and the β index of refraction 1.661. Epidote occurs as subhedral grains and is abundant in the plagioclase, from which it is derived through metamorphism. The epidote is optically biaxial; 2V is variable but near 90°, and β is 1.734. Plagioclase of bytownite composition, $Ab_{24}An_{76}$, occurs as lath-shaped crystals showing good twinning. It contains epidote grains and tiny needles of actinolite showing extinction angles up to 21°. The accessories are sphene and magnetite. A micrometric analysis made with the Wentworth-Hunt recording micrometer is given in Table 5, and a photomicrograph of a typical thin section is shown in Fig. 7, *b*.

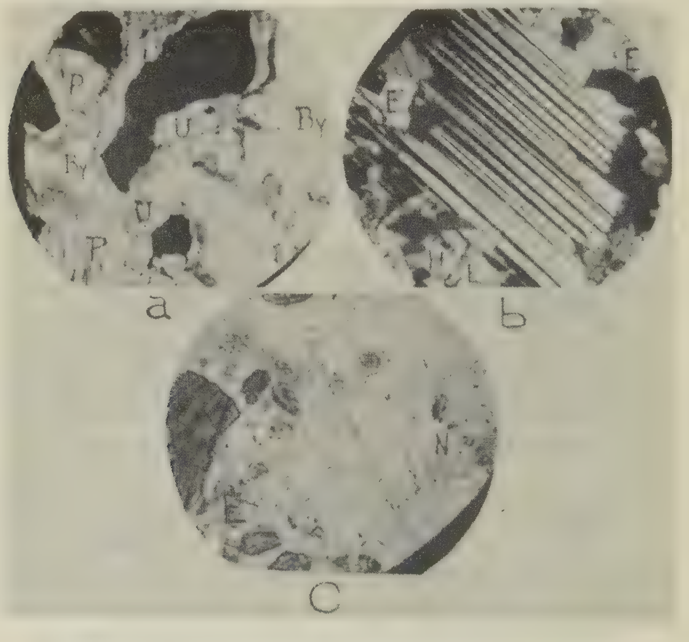

Fig. 7. Photographs of thin sections from rocks occurring at Rockdale, Maryland.

(a) *Uralitized hyperite.* Opaque areas are magnetite, pyroxene (P), showing uralite. (U) rims, set in a bytownite (By) base.

(b) Epidote amphibolite (meta-gabbro): Epidote (E) developing at the expense of plagioclase through metamorphism. Hornblende (H) exhibits lower relief.

(c) *Weathered epidote amphibolite.* Displaying "worms" of kaolinite in a base of endellite and halloysite with some nontronite.

As this rock weathers, its color lightens and it develops a mottled appearance of white areas in a grayish green base. The hornblende, still the dominant constituent, is similar to that in the fresh rock except for incipient alteration, in part to a brownish aggregate which is here condidered to be nontronite, and in part to iron oxides. The plagioclase is in various stages of freshness, but is being replaced by the clay minerals. The magnetite and sphene are accessories. The mineralogical composition is given in Table 5, and a photomicrograph of a thin section is shown in Fig. 7, *c*.

The suite of clay minerals is distinctly unique. "Worms" of kaolinite are embedded in a colorless base made up in part of a slightly birefringent halloysite and in part of isotropic endellite. It was from such pockets as these that endellite was obtained for the various physical and chemical measurements here described. The other minerals show little if any evidence of alteration. There is some nontronite in this section. It has a dirty brown color, a more or less speckled appearance, aggregate polarization, and a fibrous crenulated structure. Small spherulites of nontronite were observed. The kaolinite has the following optical properties: $\alpha=1.565$, $\beta=1.572$.

Mottled boulders of this weathered rock, originally containing endellite, had been excavated and left by the side of the road. Within the course of several weeks the boulders had disintegrated to white powdery halloysite and the unlocked accessories.

Locality No. 2. This is roughly 600 feet up the hill in the direction of Rockdale. A columnar section at this station is shown in Fig. 6. The rocks dip gently into the hill and lie above the epidote amphibolite of locality No. 1. The rock here is a uralitized hyperite (Fig. 7, *a*). A single pegmatite dike of variable width, averaging two feet, was found cutting the uralitized hyperite and dipping into the hill at an angle of about 75°. It consists of coarse muscovite, quartz, and feldspar, the whole mass being stained somewhat by iron oxides.

The uralitized hyperite is purplish gray in color, medium in grain size, and xenomorphic in texture. It consists of pleochroic hypersthene (Z = grayish green, Y = almost colorless, X = light pink), diallage, and a bytownite of slightly variable composition but approximately $Ab_{21}An_{79}$. The hypersthene grains are frequently surrounded by coronas of secondary fibrous hornblende (uralite). The accessories are magnetite, biotite, and apatite. The mineralogical composition of this rock is given in Table 5. This rock weathers to give endellite. It is thus apparent that the so-called gabbros and meta-gabbros of Baltimore County may yield endellite on weathering. Both rocks described here contain a highly calcic plagioclase (bytownite) that is altering in place to form endellite. At one of the localities the endellite has partially segregated among the weathered rock fragments. At both localities it is disseminated throughout the weathered rock and either it or halloysite is present in the "C" horizon of the soil.

The pH of the weathering rock was near 6.4 and the weathering material was wet even after a prolonged dry period of the preceding summer. The location was near the bottom of quite a long hill and the presence of rather solid rock near the surface might have caused drainage through the weathering zone. The presence of characteristic "worms" of kaolinite in a base of endellite and halloysite suggests that kaolinite may have been formed by reorganization of the halloysite which, in turn, was the product of partial dehydration of the endellite. Plagioclase feldspars, in a neutral or slightly acid system, and in the presence of water, can weather to give endellite. The tiny specks of alteration products, frequently observed on feldspars and called kaolinite, may be in part endellite or halloysite. The chemical character of the liquid phase and the ions in solution probably play an important part in determining the course of kaolinization of feldspathic materials.

SUMMARY

Halloysite, $Al_2Si_2O_5(OH)_4$, and endellite, $Al_2Si_2O_5(OH)_4 \cdot 2H_2O$, have been studied by means of chemical, electron-microscopic, *x*-ray diffraction, and petrographic methods. The observations indicate that halloysite is formed by dehydration of endellite.

Table 5. Micrometric Analyses, Expressed in Weight Per Cent, of the Several Rocks Occurring at Rockdale, Md.

	Epidote amphibolite	Weathered epidote amphibolite	Uralitized hyperite
	Per cent by weight	Per cent by weight	Per cent by weight
Hornblende	69.6	53.4	10.6 (uralite)
Plagioclase	10.3 $Ab_{24}An_{76}$	5.7 $Ab_{26}An_{74}$	48.3 $Ab_{21}An_{79}$
Epidote	18.6	3.3	
Sphene	0.4	1.0	
Magnetite	1.1	0.3	5.0
Endellite Halloysite Kaolinite	—	28.6	
Nontronite and small amounts of iron oxide stains	—	7.7	
Biotite	—		0.4
Pyroxenes	—		35.7
	100.00	100.00	100.00

Halloysite has the same type of aluminum silicate layers as kaolinite, but the layers usually are superimposed in a less orderly manner. Endellite has a structure in which kaolinite-type layers alternate with single layers of water molecules.

It is proposed that halloysite be retained as the name for materials similar to the type mineral first described by Berthier. For the more highly hydrated mineral, which has variously been called halloysite and hydrated halloysite, the name endellite is suggested in recognition of one of its discoverers.

CRYSTALLOGRAPHY OF HUREAULITE

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The rare mineral hureaulite was first discovered about 1825 by Alluaud[1] on a few small specimens from Hureaux in the Department of Haute Vienne, France. The material was described by Dufrénoy[2] and analyzed by him[2a] and by Vauquelin,[3] the former making also a rough determination of the prism angle. Des Cloizeux[4] found more material in a specimen of heterosite from La Vilate, near Chanteloube, in the same district, with crystals well enough developed to measure some of the forms with fair accuracy, and others by approximation. Hureaulite is also reported as probably occurring in Silesia. In the United States, hureaulite has been found at three localities only: Branchville[5] and Portland, Conn.,[6] and Pala, Calif.[7] The Branchville material was fairly well crystallized, and measurements on it were much better than those of Des Cloizeaux, although according to the authors, not very accurate because of the multiple habit of the crystals. From these crystals the ordinarily accepted elements of crystallization were calculated.

OCCURRENCE

The writer, in collecting recently at the Stewart mine, Pala, California, found a specimen of dark colored phosphates showing crystalline hureaulite on one of the fractured surfaces. The mineral in this crust is colorless to pale or deep amber, with none of the violet-rose or deep orange-red shown at other localities. The crystals are practically iron free, as shown by a microchemical test for iron, and confirmed by spectroscopic analysis (0.1% Fe). The limited amount of material did not permit a complete analysis, but qualitative tests showed Mn, P, and H_2O. Hardness, as determined carefully on crystals, was between 3 and 4, a value in agreement with that of Alluaud, but not with that of Des Cloizeaux, whose value of 5 has been accepted by Dana and Hintze. Hureaulite occurs as one of the near-end members of a series of alterations from some earlier mineral, perhaps lithiophilite, although none of this was observed on the hureaulite specimen. The minerals of this series are intimately intergrown, in general, so closely as to be indeterminable, although palaite was noted in veins of colorless cross fibers cutting the specimen, and blue manganiferous strengite (vilateite?) and yellow stewartite appear on the surface of cavities. Sicklerite also was tentatively identified among the earlier minerals of the series. The strengite was observed in some places overlying hureaulite, but stewartite was nowhere seen where its relative age could be determined. The palaite is clearly different in habit and appearance from the hureaulite, although it has been recently suggested[8] that the two may be identical, and it is true that most of the optical properties of the two minerals are quite similar.

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[1] Alluaud, Notices sur l'Hétérosite, l'Hureaulite (fer et manganèse phosphaté) et sur quelques autres mineraux du Department de la Haute Vienne: *Ann. de Sci. Nat.*, **8,** 334–354 (1826).

[2] Dufrénoy, *Annales des Mines*, 2d ser., **7,** p. 137.

[2a] Dufrénoy, Sur deux nouveaux phosphates de manganèse et de fer: *Ann. de Chemie et de Physique*, 2d ser. **41,** 338 (1829).

[3] Vauquelin, Analyse de l'Hureaulite, mineral trouvé dans la commune d'Hureaux: *Ann. de Chemie et de Physique*, 2d ser., **30,** 302 (1825).

[4] Des Cloizeaux, Determination des formes cristallines et des propriétés optiques de l'Hureaulite: *Ann. de Chem. et de Physique*, ser. 3, **53,** 293 (1858).

[5] Brush, G. J., and Dana, E. S., On the mineral locality of Branchville Conn. 5th Paper: *Am. Jour. Sci.*, 3d ser., **39,** 207 (1890).

[6] Shairer, J. F., Lithiophilite and other rare phosphates from Portland Conn.: *Am. Mineral.*, **11,** 101–104 (1926).

[7] Schaller, W. T., New manganese phosphates from the gem tourmaline field of southern California: *Jour. Wash. Acad. Sci.*, **2,** 143–145 (1912).

CRYSTALLOGRAPHY

The crust of hureaulite was in part made up of excellent crystals, so that it has been possible to make rather accurate measurements on them. Calculations from these measurements has led to a slight modification of the lengths of the *a*- and *c*-axes, and of the value of β, with a doubling of the length of the *c*-axis.

The crystals are small, none of them much over one mm. in longest dimension, and appear in two general habits, both somewhat elongated parallel to *c*. One habit is tabular parallel to {100}, the other stout prismatic, with nearly equal development of {100} and {110}. A typical crystal is shown in Fig. 1. In general, the faces are smooth and of good quality so that the reflections are good to fair. None are strongly striated as described by Des Cloizeaux,[9] but occasionally vicinal faces are present so that the signals are multiple. Seventeen crystals in all were measured and Table 1 shows the average readings for faces used in calculating the crystallographic elements.

These values have been heavily weighted in favor of one particularly good crystal, especially for the forms *m*, *c*, and α. It will be noted that the average of all measured values for ϵ is not in very good agreement with the calculated value, although the selected better signals are very close. This lack of agreement is due to the fact that the pyramid face is very

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[8] Mason, Brian, Minerals of the Varuträsk pegmatite, XXIII: Some iron manganese phosphate minerals: *Geol. För. Förh.*, **63**, 117–175 (1941). (Abstr. *Am. Mineral.*, **26**, 682, 1941).

[9] *Loc. cit.*, p. 296.

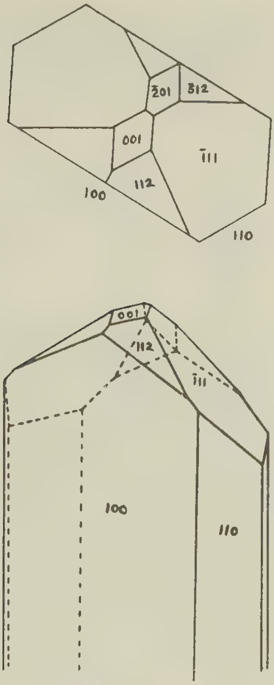

FIG. 1

TABLE 1. FORMS USED IN CALCULATION OF AXES

Form	No. readings	Qual.	Weighted average		Calculated	
			ϕ	ρ	ϕ	ρ
c 001	3	A	90°00′	6°40′	90°00′	6°40′
m 110	30	B	27 35	90 00	27 32½	90 00
α $\bar{2}01$	6	A	−90 00	44 17	−90 00	44 17
δ 112	10	B	36 35	33 09	36 40½	33 08
ϵ $\bar{1}11$	7	B	−22 17	48 23	−22 17	48 32
	(15	C	−22 42	48 18—average of all good signals)		

frequently represented by a vicinal face of a quality about equal to the true one, sometimes alone, sometimes occurring with the latter, so that it is not always possible to distinguish one from the other. Accordingly, the calculations have been weighted in favor of the other forms. The lengths of the axes derived from these calculations agree fairly well with those of Brush and Dana,[10] if their length of *c* is doubled, and also with those of

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[10] *Loc. cit.*, p. 208.

De Schulten[11] on pure synthetic crystals. In both these cases, however, the available material was not particularly good, although better than Des Cloizeaux's, and it has seemed justifiable to the writer to offer his own values as more nearly the correct ones for this mineral. The comparative values are shown below:

TABLE 2. AXIAL RATIOS

	a	b	c	β
Brush and Dana	1.9192	1	$\frac{1}{2}$(1.0490)	95°59′
De Schulten	1.9048	1	$\frac{1}{2}$(1.0378)	96 28
Murdoch	1.9307	1	1.0470	96 40

Dana's choice of axial lengths results in rather complex indices, and accordingly Goldschmidt, in the *Winkeltabellen*, chose a reversed orientation, a doubling of c, and a higher value for β giving fairly simple indices, but a rather steeply inclined base. If, however, we keep Dana's orientation, but double the length of his c-axis, the indices become essentially as simple as Goldschmidt's with the added advantage that {001} is more nearly horizontal, as it should be according to convention. The transformation formulae for the different settings are as follows:

Dana to Murdoch	100/010/002
Goldschmidt to Murdoch	$\bar{1}0\bar{1}$/010/001

X-ray oscillation photographs, taken about the vertical axis, confirm this choice of axial lengths. The measurements give the following cell size: a_0 17.42 Å, b_0 9.12 Å, c_0 9.50 Å. This corresponds to $a:b:c = 1.908:1:1.040$, which is in reasonably close agreement with the crystallographic values.

The space group, from rotation photographs, is probably C_{2h}^4, the unit cell carries four molecules, and the calculated specific gravity is 3.23. This value checks very closely with the determined values which range from 3.198 to 3.149. The small amount of material available did not allow direct determination of specific gravity for the Pala crystals.

NEW FORMS

On the measured crystals the following recognized forms were observed: a, m, ϵ, k, α, δ, c, q, and in addition a number of new forms. These are listed in Table 3, which shows the number of times each was observed, the quality and position of each. Some occurring only once are in such good position as to be considered acceptable, likewise, one appearing six times, although with poorer signals. These have been given letters, while others, occurring only once, with poor signals, are listed, but as doubtful forms.

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[11] De Schulten, A., Production artificielle de hureaulite et de la hureaulite de cadmium: *Min. soc. franc., Bull.*, **27**, 123 (1904).

TABLE 3. NEW FORMS

Form	No. times	Quality	Measured		Calculated	
			ϕ	ρ	ϕ	ρ
n 580	1	B	18°20′	90°00′	18°03′	90°00′
h 760	1	B	31 18	90 00	31 19	90 00
g 111	3	D	32 13	50 01	32 20	51 06
	3	E	38 35	51 40		
s 311	1	C	56 55	63 44	59 11	63 55½
t 511	1	A	67 49	72 14	69 48½	71 45
? 611	1	D	69 50	75 00	72 51	74 16
? 12.1.1	1	D	79 21	81 30	81 05	81 34½
? 232	1	D	23 28	57 25	22 53	59 36
? $\bar{6}13$	1	E	−70 14	48 15	−70 29½	46 16

The full angle table for hureaulite, with the revised values, is given in Table 4.

TABLE 4

$a:b:c=1.9307:1:1.0470$ $\beta=96°40'$
$p_0=0.5423$ $q_0=1.0400$ $r_0=1$ $\mu=83°20'$
$r_2=0.9615$ $p_2=0.5215$ $q_2=1$
$p_0'=0.5460$ $q_0'=1.0470$ $x_0'=0.1169$

Form	ϕ	ρ	ϕ_2	$\rho_2=B$	C	A
c 001	90°00′	6°40′	83°20′	90°00′	0°00′	83°20′
a 100	90 00	90 00	0 00	90 00	83 20	0 00
b 010	0 00	90 00	0 00	0 00	90 00	90 00
n 580	18 03	90 00	0 00	18 03	87 55	71 57
m 110	27 32½	90 00	0 00	27 32½	86 55	62 27½
h 760	31 19	90 00	0 00	31 19	86 31½	58 41
α $\bar{2}01$	−90 00	44 17	134 17	90 00	50 57	134 17
β $\bar{5}02$	−90 00	51 18	141 18	90 00	57 58	141 18
g 111	32 20	51 06	56 31½	48 53	47 46½	65 24
ϵ $\bar{1}11$	−22 17	48 32	113 13½	46 06	51 20	106 30
δ 112	36 40½	33 08	68 42	64 00	29 36	70 57
p 113	40 34½	24 40½	73 21½	71 31	20 56	74 14½
s 311	59 11	63 55½	29 40½	62 36	58 15	39 31
z $\bar{3}11$	−55 27½	61 33½	146 40½	60 05½	67 10	136 25
t 511	69 48½	71 45	19 21	70 52	65 30½	26 57½
k $\bar{5}12$	−67 14½	53 32	141 18	71 52	59 43	137 52
q $\bar{5}34$	−35 46	44 03½	119 29½	55 39	48 12	113 59
l $\bar{4}21$	−44 45½	71 16	154 17	47 44½	76 01	131 49½

The writer wishes to thank Dr. J. D. McCullough, of the department of Chemistry, University of California, Los Angeles, for taking the x-ray phogographs and assisting in the calculations. Dr. W. T. Schaller, of the U. S. Geological Survey, has been kind enough to waive his prior rights on the description of hureualite from Pala, which he was the first to find, and to permit the publication of this note. The spectroscopic analysis was made possible by a grant from the Research Fund of the University of California.

GRUNERITE IN WESTERN AUSTRALIA*

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INTRODUCTION

Recent studies of the older pre-Cambrian banded iron formations or banded ironstones, banded hematite quartzites, jaspilites or "jasper bars," as they are variously called in Western Australia, have revealed that where these have been subjected to high grade metamorphism, recrystallization is characterized by the development of the iron-rich amphibole, grunerite. This mineral has been found in many places throughout the State, and a description by the writer of its associated minerals and of the petrology of the rocks in which it occurs, will, it is hoped, be published shortly.

These metamorphosed banded iron formations in Western Australia show close affinities with the grunerite-bearing rocks of the Lake Superior Region in the United States. In the following pages is given brief descriptions of the occurrence of grunerite in several localities in Western Australia, together with an account of its mineralogy and chemical composition, and of its associated minerals.

DESCRIPTION OF OCCURRENCES

All specimens of grunerite so far recorded in Western Australia come from metamorphosed banded iron formations. Minerals with which it has been found most commonly associated are magnetite, quartz, blue-green hornblende, hedenbergite or iron-rich hypersthene, garnet, and to a much lesser extent, fayalite. The form, structure and mineral associations of the grunerite-bearing rocks of Western Australia usually indicate recrystallization of original banded ferruginous sedimentary material at high temperatures with little or no directed pressure, characteristic of contact thermal metamorphism (Fig. 3). However, some occurrences show evidence that recrystallization took place under fairly high directed pressures, indicative of regional metamorphic conditions (Fig. 4).

R. T. Prider (1)† has described the occurrence of a grunerite having optical properties indicating a composition near cummingtonite, from banded ironstone xenoliths in granite gneiss near Toodyay (Fig. 1). In another xenolith in this vicinity the place of grunerite is taken by iron-rich hypersthene.

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* Extracted from a portion of a thesis accepted in part fulfillment of the requirements for the degree of Doctor of Science in the University of Western Australia.

† Numbers in parentheses relate to references collected at the end of the paper.

At Bolgart, some 22 miles north of Toodyay, a very similar grunerite in banded magnetite-grunerite quartzite is also found occasionally intergrown with iron-rich hypersthene.

At Clackline, 12 -13 miles to the south of Toodyay, is a series of metamorphosed banded ferruginous quartzites interbedded with garnetiferous and sillimanite-bearing mica schists. These ferruginous quartzites contain interbanded layers alternately rich in quartz and in cummingtonitic grunerite associated with magnetite, garnet (almandine), and a strongly pleochroic blue-green hornblende, which will be mentioned later.

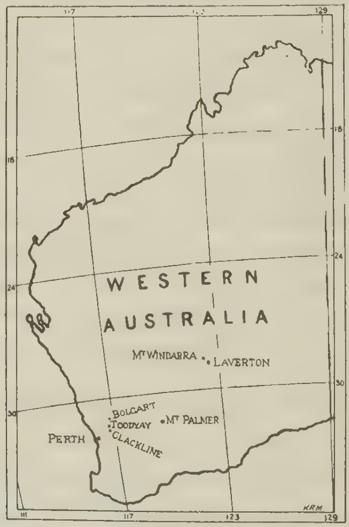
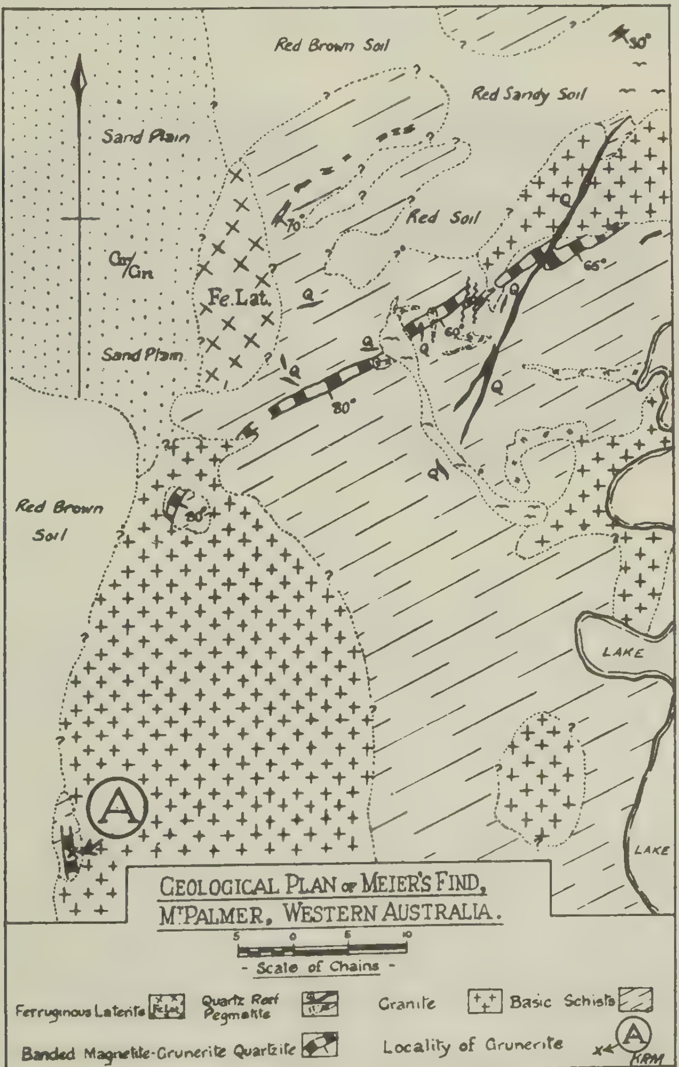


FIG. 1. Locality map.

Banded iron formations or "jasper bars" are very abundant in the gold-bearing Older Greenstone Series in the Central Goldfields of Western Australia, and grunerite-bearing rocks are characteristic of the more highly metamorphosed regions. The best exposures of these rocks so far located are in the Mt. Palmer district of the Yilgarn Goldfield (Fig. 1). Here the beds of metamorphosed banded ironstone (meta-jaspilites) consist of banded magnetite-grunerite quartzites containing layers locally rich in hedenbergite and fayalite. These rocks are interbedded with recrystallized basic lavas and tuffs (amphibolite schists), ultra basic rocks (anthophyllite schists), and thin bands of argillaceous sediments (garnetiferous and andalusite-bearing mica schists), and intruded by numerous bodies of biotite granite and later quartz and pegmatite reefs. The rocks in this vicinity are for the most part comparatively fresh and unweathered and they provide excellent material for petrological investigations.

GRUNERITE FROM MEIER'S FIND, MT. PALMER

Material for analysis was selected from outcrops of banded magnetite-grunerite quartzite from the vicinity of Meier's Find, 3 miles south of Mt. Palmer. The geology of this area is illustrated in Fig. 2. The granite has completely engulfed portions of the banded ferruginous sediments



Compiled from Maps by K.R.Miles, 1940, and R.A.Hobson, 1936.

FIG. 2.

and associated basic amphibolite schists, leaving here and there small remnants or xenoliths of the older rocks.

The amphibole in these metamorphosed iron formations usually occurs in surface specimens as narrow bands of golden-brown to almost straw-colored silky lustred flakes and short prismatic crystals, associated with layers of black metallic iron ore. Occasionally fresher specimens are found, however, in which the amphibole is in masses of clear, rather grayish-green to light olive-green crystals.

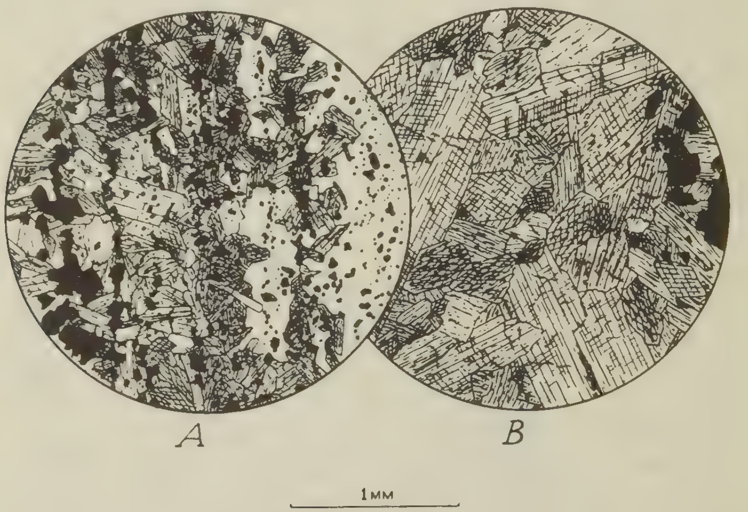


Fig. 3. Grunerite in banded magnetite grunerite quartzite, Meier's Find, Western Australia (Spec. 2/1740). *A*. Slice cut normal to banding. Note random orientation of the amphibole crystals. The original bedding is indicated by the parallel strings of magnetite crystals. *B*. Portion of a coarser grained grunerite-rich layer. Larger tabular plates of grunerite cut approximately parallel to (010) show well developed prismatic cleavage and characteristic fine cross striation parallel to (001).

The specimen from which grunerite for analysis was obtained came from a small outcrop partly enclosed by granite in the south west corner of the area, illustrated in Fig. 2. This rock is well banded, consisting of alternating layers of interlocking finely crystalline amphibole ranging from less than 1.5 mm. up to fairly coarsely crystalline bands over 20 mm. thick, enclosing thin bands of tiny black magnetite crystals and set in layers of glassy, clear to gray or brownish, fine grained quartz up to almost 5 mm. thick.

In thin section the rock appears granoblastic gneissic and the banded structure is well pronounced. The intercalated quartz bands form a clear mosaic often sprinkled with minute dust-like aggregates of iron ore. These alternate with bands rich in almost colorless grunerite, often associated with very minor quantities of a blue-green strongly pleochroic amphibole, and magnetite. The iron ore usually occurs in irregular parallel strings of loosely connected crystals passing evenly through the amphibole-rich bands (Fig. 3*A*) and also as narrow layers of grains ranging in size from minute particles up to idioblastic aggregates averaging .1–.2 mm. in diameter, enclosed in the quartz-rich bands. The iron ore grains in the different bands are more or less graded, the most coarsely crystalline masses usually being associated with the amphibole-rich layers.

The grunerite usually occurs in aggregates of interlocking short prismatic laths and diamond shaped basal sections, very light grayish-brown to colorless, lying in random orientation. The grain size of this amphibole varies somewhat in the different bands. For bands up to 1.5 mm. thick individual laths average .2–.3 mm. long, but in the coarser bands crystals may reach a length of over 2 mm. The typical random orientation of the crystals (decussate structure) and their characteristic form and cleavage are illustrated in Fig. 3*B*, which shows a portion of a coarse amphibole-rich band. Prism faces are usually well developed but the terminations of individual crystals are generally irregular. They show very good (110) cleavage and very characteristic well developed cross striations, which on sections cut approximately parallel to (010) make an angle of about 73° with the intersection of (110), and on sections parallel to (100) are approximately normal to (110). Thus these striations are apparently parallel to (001). Basal sections are characteristically diamond shaped with the perfect (110) cleavages intersecting at 56° and 124°. In no instance was any development of (010) faces seen. Prismatic sections frequently show irregular cross fractures.

The mineral is very weakly colored and feebly pleochroic with $X =$ colorless to pale yellow; $Y =$ pale yellow-brown to yellowish-gray; $Z =$ pale yellow to pale green. Absorption $Y > Z > X$.

Many of the larger crystals show a grayish-brown cloudiness indicative of incipient oxidation, particularly along the cross fractures.

Twinning, both simple and multiple, on (100) as twin plane is very common, and very characteristic.

The refractive indices of this mineral were determined by the immersion method using mixtures of α-monobromnaphthalene and methylene iodide, with a sodium light. The indices of the mixtures were determined with the use of a tested Herbert Smith refractometer. These are:

$$\begin{aligned} \alpha &= 1.673 \pm .002 \\ \beta &= 1.694-{}^{*} \\ \gamma &= 1.711 \\ \gamma-\alpha &= .038 \\ Y &= b;\ Z\wedge c = 13\tfrac{1}{2}-14^\circ \end{aligned}$$

2V large (about 85°). Optical character −. Optical axial plane is parallel to (010). Dispersion is weak, r slightly $> v$.

Without a universal stage the writer was unable to determine the optic axial angle directly. From the refractive indices, however, using the approximate formula: $\cos V_\alpha = \sqrt{\beta-\alpha/\gamma-\alpha}$, we find that 2V = approximately 84°.

The above data indicate grunerite with a small amount of the cummingtonite molecule—probably containing about 83% of $FeSiO_3$. This conclusion is borne out by the chemical analysis (Tables 1 and 3).

In its optical properties this mineral appears to be intermediate in character between a specimen from Mt. Humbolt, Lake Superior, Michigan, described by S. Richarz in 1927 (2) and a mineral from La Mallière near Collobrières, France, analyzed by S. Kreutz in 1908 (3). It is very close optically to grunerite from Pierrefitte, Hautes-Pyrénées, France, described by H. V. Warren in 1931 (4) (Table 3).

The grunerite from the Meier's Find rock was isolated for analysis by crushing to pass a 150 mesh sieve, and by treatment with a strong hand-magnet to remove the bulk of the magnetic iron ore, and finally it was freed from the light minerals by repeated separations in bromoform (G. = 2.9). The remaining material was cleaned by boiling in a fairly strong hydrochloric acid solution. Inspection revealed that there still remained about 5 per cent impurity in the form of grains of a dark blue-green amphibole. These were removed by hand picking under a fairly high power lens. The analysis of the resulting pure sample of grunerite (Table 1) was made for the writer in the Western Australian Government Chemical Laboratory.

No fluorine estimation was made on this analysis but a subsequent determination by Mr. G. L. Miles in the Department of Chemistry, University of Western Australia, indicated $F < 0.05\%$. It being assumed then that the fluorine content was sufficiently low to be neglected, the analysis of this grunerite was arranged so that the constituents were in order of increasing effective radius and the structural formula calculated on a basis of 24 (O, OH, F) (Table 1). This gave the formula $(OH)_{2.36}(Fe'', Mg, Fe''', Al, Ca, Mn)_{6.75}(Si, Al)_8O_{22}$ which agrees fairly well with the ideal Warren formula for a monoclinic amphibole low in alkalies (5).

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[*] Owing to the difficulty of obtaining a perfectly oriented section there is some doubt as to the true value of β.

This gives the structural formula:

$$(OH)_{2.36}(Fe'', Mg, Mn, Fe''', Ca, Al)_{6.75}(Si, Al, P)_8O_{22}.$$

The chief points of difference are the slightly high (OH) value and the very slight deficiency in (Fe'', Mg, etc.). Possibly the slight excess of H_2O may represent an incipient hydration of the mineral whilst most of the small Fe_2O_3 content shown in the analysis has probably been formed due to oxidation, as it is impossible to avoid a slight cloudiness in even the freshest material analyzed.

Table 1. Analysis and Calculation of Grunerite from Meier's Find

	Wt. %	Molecular Proportions	Metal atoms on basis of 24 (O, OH, F)	Metal Groups
SiO_2	50.37	.838	7.969	8.00
P_2O_5	.02	.0002	.004	
Al_2O_3	.54	.005	$.095\begin{cases}.027\\.068\end{cases}$	
Fe_2O_3	.56	.003	.057	6.75
MgO	4.47	.110	1.046	
FeO	40.08	.557	5.306	
MnO	1.07	.015	.142	
CaO	.83	.014	.133	
H_2O+	2.24	.124	2.858	2.36
H_2O-	.20			
	100.38			

In Table 2 the analysis of the Meier's Find mineral is compared with those of grunerite from different localities in North America and France, and one from Sweden. The essential characteristics of grunerite are the very low alkali content, the low alumina and ferric iron oxide, and the high ferrous iron oxide and silica contents. MgO replaces FeO in varying degrees while Al_2O_3 sometimes replaces a little of the silica, but always in very minor amounts. The analysis of Meier's Find grunerite demonstrates all these features clearly. The Swedish mineral (Table 2, No. 7) differs most from normal grunerite in that MnO and MgO have replaced a considerable quantity of the ferrous iron. This mineral should thus probably be called manganiferous cummingtonite or dannemorite. The grunerite from Rockport, Mass. (Table 2, No. 5) consists of almost pure ferrous silicate and approaches very close to the theoretical formula $H_2Fe_7(SiO_3)_8$ or $(OH)_2Fe_7\,Si_8O_{22}$.

TABLE 2. ANALYSES OF GRUNERITE FROM WESTERN AUSTRALIA, NORTH AMERICA, FRANCE AND SWEDEN

	1.	2.	3.	4.	5.	6.	7.
SiO_2	50.37	48.53	47.17	46.42	47.54	50.79	50.74
Al_2O_3	.54	1.02	1.00	.25	.20	.34	.88
Fe_2O_3	.56	1.14	1.12	.09	.71	.89	1.80
FeO	40.08	39.20	43.40	42.60	47.25	38.43	24.13
MnO	1.07	.66	.08	2.23	2.14	1.12	7.38
MgO	4.47	4.06	2.61	3.12	.04	6.50	10.57
CaO	.83	1.31	1.90	1.51	Nil	Nil	2.00
Na_2O	Nil	1.06	.47	.70	.29	Tr	.22
K_2O	Nil	.19	.07	.43	.11	Nil	.08
H_2O+	2.24	1.71	2.22	1.78	1.55	2.00	1.94
H_2O-	.20	—	—	.14	—	—	—
TiO_2	Nil	—	—	.15	—	—	—
P_2O_5	.02	—	—	—	—	—	—
CO_2	Nil	—	—	—	—	—	—
C	—	—	—	.65	—	—	—
F_2	Nil	—	.07	—	.01	—	.07
	100.38	98.88	100.11	100.07	99.84	100.07	99.87
Sp. Gr.	3.45	3.44	3.518	—	3.597	3.443	3.337
Analyst	C. R. Le Mesurier	S. Richarz	S. Kreutz	E. G. Radley	Bowen & Schairer	A. Bygden	K. Johansson

1. Grunerite from 1 mile south of west corner Peg. G.M.L. 3647, Meier's Find, Yilgarn Goldfield, Western Australia.
2. Grunerite from ½ mile south of R.R. Station at Mt. Humbolt, Michigan (2, p. 151).
3. Grunerite from La Mallière near Collobrières, France (3, p. 910).
4. Grunerite (from schist). Pierrefitte, Hautes Pyrénées, France (4).
5. Grunerite from Rockport, Massachusetts (6, p. 545).
6. Grunerite from Cummington, Massachusetts (7).
7. Grunerite (dannemorite) from Uttersvik, Nävekvarn, Sweden (7).

The chemical and optical data for the Meier's Find grunerite agree fairly well with the results of previous work, and fit without serious discrepancy into the curves for iron-rich hydroxy-amphiboles of the grunerite series of Bowen and Schairer (6, Fig. 1), and for the manganese-poor grunerites and cummingtonites plotted by Sundius (7, Fig. 1).

Table 3 summarizes the optical data for the minerals whose analyses are given in Table 2. The molecular percentages of the principal constituents $FeSiO_3$, $MgSiO_3$, $MnSiO_3$ and $CaSiO_3$, neglecting the small percentages of other constituents, have also been added in this Table. These figures do not take into account the regular and definite quantities of combined water shown in the analyses of Table 1. Bowen and Schairer, in discussing this point recognized the hydroxyl as an essential constituent in these amphiboles (6, p. 548) and they have calculated the composition of the Rockport grunerite, etc., in terms of the two molecules $(OH)_2(Fe, Mn)_7(Si_4O_{11})_2$ and $(OH)_2Mg_7(Si_4O_{11})_2$. It may be noted that neither of these writers nor N. Sundius, who in 1931 compared the optical and chemical properties of the Mn-poor grunerites and cummingtonites with those of the Swedish manganiferous members (7), have considered lime as holding an essential place in the molecular structure of the grunerites.

The Pierrefitte and Mt. Humbolt minerals appear to be closest in both optical and chemical properties to the Meier's Find grunerite, the rather higher birefringence of the last probably being due to the slight increase of $FeSiO_3$ at the expense of $MnSiO_3$ compared with the former.

TABLE 3. COMPOSITION AND OPTICAL PROPERTIES OF THE GRUNERITES OF TABLE 2

	Meier's Find	Mt. Humbolt	Collobrières	Pierrefitte	Rockport	Cummington	Uttersvik
$FeSiO_3$	79.9	80.4	85.8	81.4	95.4	75.0	43.3
$MgSiO_3$	16.0	14.8	9.2	10.6	.1	22.8	34.1
$MnSiO_3$	2.0	1.4	.2	4.3	4.5	2.2	18.0
$CaSiO_3$	2.1	3.4	4.8	3.7	Nil	Nil	4.6
α	1.673	1.666	1.672	1.676	1.686	1.666	1.655
β	1.694−	1.684	1.697	1.693	1.706	1.684	1.672
γ	1.711	1.700	1.717	1.707	1.729	1.704	1.686
$\gamma-\alpha$	.038	.034	.045	.031	.043	.038	.030
2V	84° (Calc.)	85°	80–84°	85°15′	86°	90°	85.3°
$c:\gamma$	$13\frac{1}{2}$–14°	14–15°	10–11°	13°22′	10°	14°	15.4°

GRUNERITE FROM MT. WINDARRA

Near Mt. Windarra, about 14 miles north west of Laverton (Fig. 1) in the Mt. Margaret Goldfield, grunerite has been found in several beds of banded magnetite-grunerite quartzite enclosed in granitic gneiss.

The amphibole in slightly weathered surface specimens of this rock has a golden brown color, due apparently to a surface oxidation and hydration to limonite, since the powdered mineral, on treatment with hot HCl changes to a pale green, the surface stain being completely dissolved away. The grunerite occurs in narrow bands associated with granular magnetite intercalated between layers of quartzite. It is occasionally intergrown with a little blue-green pleochroic amphibole. Individual crystals of grunerite in these bands show a high degree of parallel alignment or orientation, indicative of growth under regional directed pressure (Fig. 4). The general form of the mineral is very similar to the Meier's

Find grunerite. Prismatic plates show perfect (110) cleavage and the characteristic (001) cross striation. An irregular cross fracture is also fairly common. Sections cut normal to the *c* axis (Fig. 4*A*) show the (110) cleavages intersecting at 56°, also occasionally a perfect (010) parting. Polysynthetic twinning on (100) is very common. Under the microscope it was noticed that the mineral here and there varied somewhat in its intensity of coloring from an almost colorless to a pale green, and in places it appeared that the colorless mineral was intergrown (sometimes in optical continuity) with the colored mineral.

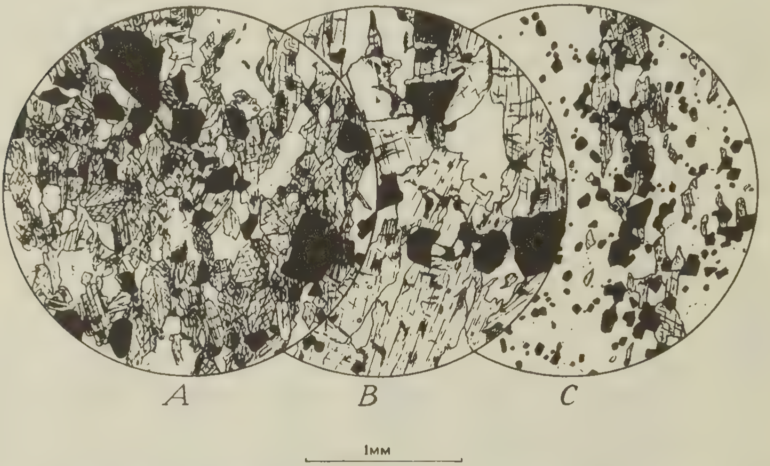

FIG. 4. Grunerite in banded magnetite grunerite quartzite, Mt. Windarra, Western Australia (Spec. L 180). Shows the form, structure and strongly oriented nature of the xenoblastic grunerite, indicative of growth under directed pressure (regional metamorphism). *A*. Slice cut normal to strike and dip of the banding (original bedding planes). Basal sections of grunerite predominate. Note the abundant twin planes on (100). *B*. Slice cut approximately parallel to strike and dip of bedding showing broad plates of grunerite cut parallel to (100). *C*. Slice cut approximately normal to the directions *A* and *B*, showing elongated ragged sections cut parallel to (010).

An attempt was made to separate these minerals for chemical analysis and after crushing to pass 150 mesh, extraction of magnetite with a hand magnet and removal of the light minerals by repeated bromoform separations, it was found that the resulting powder could be divided into two fractions by treatment with a strong electromagnet.

The magnetic fraction was a light straw color (gravity approx. 3.35). The non-magnetic powder was a pale green color (gravity about 3.25) and in the ratio non-magnetic to magnetic of about 8:3.

The lighter colored mineral was very weakly pleochroic with X = colorless; Y = pale yellowish; Z = very pale greenish. Absorption $X<Y=Z$. Optics are:

$\alpha = 1.663 \pm .002$
$\beta = 1.680$
$\gamma = 1.696$
$\gamma - \alpha = .033$
$Z \wedge c = 15\text{–}15\frac{1}{2}°$; $Y = b$. Optical character negative;
2V large (about 85°). Optic axial plane parallel to (010).
Dispersion not noticeable.

The above data indicate a grunerite near cummingtonite and probably containing approximately 65% $FeSiO_3$. Its optical properties appear fairly close to those of the Mt. Humbolt grunerite of Richarz and of the Cummington grunerite (Table 3), the principal difference being a slightly weaker birefringence.

A partial chemical analysis by G. L. Miles of the Department of Chemistry, University of Western Australia, gave the following:

$Fe_2O_3 = 1.8$ %
$FeO = 29.51$
$MnO = 1.6$
$MgO = 9.7$
$CaO = 1.7$
SiO_2 about 51%

Recalculated in terms of the molecular percentages of the four principal meta silicates—i.e. of Fe, Mn, Mg and Ca, this analysis gives:

$FeSiO_3$	58.2
$MnSiO_3$	3.2
$MgSiO_3$	34.4
$CaSiO_3$	4.2 (compare Table 3)

This indicates a grunerite very close to cummingtonite (i.e., 60% $FeSiO_3$) in which an appreciable amount of ferrous iron has been replaced by magnesium (compare with Tables 2 and 3). The Mt. Windarra mineral is distinctly higher in magnesia than the Meier's Find grunerite and in this respect more nearly approaches the Swedish Uttersvik mineral.

The darker green colored amphibole from Mt. Windarra differs from the lighter colored magnetic mineral principally in slightly stronger pleochroism and absorption colors, and in weaker refringence and birefringence. Approximate refractive indices determined were:

$\alpha = 1.653 \pm .002.$
$\gamma = 1.673+$
$\gamma - \alpha = .020$; optical character negative;
$Z \wedge c = 15\frac{1}{2} - 16°$; $Y = b$.

These optical properties suggest an iron-rich actinolite, the principal discrepancy being a rather low value for the birefringence.

A partial analysis by G. L. Miles gave:

Fe_2O_3	1.0 %
FeO	19.10
MnO	0.63
MgO	7.38
CaO	5.95

This analysis bears out the optics and indicates an actinolite in which ferrous iron has replaced a portion of both the lime and the magnesia. As with the associated grunerite, the ferric iron content is low.

The Blue-Green Amphibole

Frequent mention has been made in the foregoing pages of the presence of a blue-green, strongly pleochroic amphibole associated with the grunerite in metamorphosed banded iron formations. This dark colored mineral is occasionally found moulded upon or growing in optical continuity with crystals of grunerite, though it more frequently occurs as small xenoblastic interstitial grains. In garnetiferous phases of the banded magnetite grunerite quartzites found at Clackline and near Mt. Palmer at Meier's Find and Heaney's Find (3 miles N.N.E. of Mt. Palmer), narrow bands rich in dark colored amphibole usually enclose clusters of dark red garnet, probably almandine. These bands probably represent thin clayey (aluminous) layers in the original ferruginous sediment.

This amphibole is jet black colored in mass. In thin sections it appears to have a form similar to the grunerite and usually occurs in subhedral plates showing perfect (110) cleavages, which in basal sections intersect at about 56° and 124°. Terminations on prismatic laths are usually irregular. The cross striation (001) on prismatic plates, so characteristic of the grunerite, is seldom seen. Simple twinning on (100) is uncommon and polysynthetic twinning is very rare.

Pleochroism is very strong; X = light green to yellowish-green; Y = dark olive green; Z = intense blue-green. The strong absorption masks interference colors, $Z \geqq Y > X$. Refractive indices of the mineral from Clackline gave:

$$\alpha = 1.673 \pm .002$$
$$\gamma = 1.701$$
$$\gamma - \alpha = .028$$
$$Z \wedge c = 21\text{-}22^\circ;\ Y = b.$$

Optical character negative; 2V large (about 80°).

The strong blue-green color in amphiboles has been attributed to the presence of either appreciable quantities of iron in the ferric condition (8) (9) and (10), or of a considerable soda content.

To test these possibilities an attempt was made to isolate a small quantity of the blue-green amphibole from the heavy fraction of the Meier's Find grunerite described above. With the aid of a strong electromagnet it was found possible to remove most of the grunerite and magnetite leaving a fairly pure concentrate of blue-green amphibole. A micrometric analysis of the final product gave the following composition:

Blue-green amphibole 87.8%, grunerite 11%, magnetite (about) 0.5%, other minerals $<0.5\%$. Other minerals consisted of a few grains of quartz and zircon.

About .8 gram of the dark colored amphibole was so obtained. A partial analysis by G. L. Miles gave the following figures, after the necessary corrections for the impurities present had been made:

Fe_2O_3	8.7%
FeO	25.0
Na_2O+K_2O	$<$ .1

The notable quantity of ferric iron and the almost total absence of soda confirm the opinion that the ferric iron is responsible for the strong blue-green coloration in this amphibole.

Finally, it may be of interest to note here that S. Richarz in 1927 recorded the presence of a variety of blue-green amphibole often found in parallel intergrowth with grunerite, in banded ferruginous amphibole-quartz rocks in the Lake Superior Region at Michigamme and Republic, Michigan (2, p. 154), and also from similar rocks in the Marquette District. According to Richarz this Lake Superior amphibole is strongly pleochroic with X = yellowish; Y = olive-green; and Z = blue-green, and has a birefringence about equal to that of common hornblende.

SUMMARY

In the foregoing pages a number of occurrences of the mineral grunerite in Western Australia have been described for the first time. Grunerite has been found only amongst the metamorphosed banded iron formations of the Older Greenstone Series of Western Australia. It has been formed as a result of the interaction of iron and silica during recrystallization of these rocks under conditions of both regional and contact thermal metamorphism. These metamorphosed banded iron formations in Western Australia appear very similar in mineralogical and chemical composition (and probably in origin) to the grunerite-bearing rocks of the Lake Superior Region.

The mineralogy, optical properties and chemical composition of several grunerites in Western Australia have been discussed in some detail, and a complete analysis and several partial analyses given. A brief description of a blue-green hornblende often associated with the grunerite in these rocks has also been added. The strong blue-green interference color displayed by this latter amphibole is shown to be due to a fairly high ferric iron content.

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The writer is much indebted to his brother, Mr. G. L. Miles of the Department of Chemistry, University of Western Australia, for his assistance in the preparation of a number of partial analyses included in the foregoing pages. He also thanks Dr. R. T. Prider of the Department of Geology, University of Western Australia, for many helpful discussions and suggestions during the determination of the optical data for this paper.

This work was carried out partly in the laboratories of the Geology Department, University of Western Australia, and partly in the Geological Survey of Western Australia, and the writer acknowledges his indebtedness to Professor E. de C. Clarke, and the Government Geologist, Mr. F. G. Forman, for making all facilities available to him.

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ON AMBLYGONITE

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Abstract

Two new occurrences of amblygonite at Hebron and Newry, Maine, furnished measurable crystals. New elements based on *x*-ray study required a new orientation from that of Dana. Transformation from Dana to Richmond and Wolfe is as follows: 001/011/100. $a:b:c=0.7255:1:0.7028$; $\alpha=111°\ 59\frac{1}{2}'$, $\beta=97°\ 46\frac{1}{2}'$, $\gamma=68°\ 16\frac{1}{2}'$, $a_0=5.18\text{Å}$, $b_0=7.11\text{Å}$, $c_0=5.03\text{Å}$, $\alpha=112°\ 02\frac{1}{2}'$, $\beta=97°\ 49\frac{1}{2}'$, $\gamma=68°\ 07\frac{1}{2}'$. The cell contains $2[LiAlPO_4(OH,F)]$. The new angle table contains, besides the forms known previously, 10 new forms.

Amblygonite, a fluophosphate of aluminum, sodium and lithium, is an important constituent of lithium-bearing granite pegmatites. It has been found in many localities and is of commercial importance because of its high lithium content. The crystals are often of great size, and cleavage masses are familiar to all students of pegmatite minerals. But, although its chemistry and general physical properties are well known, detailed description of its crystal morphology has been lacking because adequate material for its study has never hitherto been found. It is now possible to supply this deficiency through the study of two new occurrences of amblygonite in the towns of Hebron and Newry in Maine. The two suites of crystals are widely different in character but yield crystallographic data which are entirely harmonious. As the material came to the Harvard Mineralogical Museum at different periods, the study of the two occurrences has been carried on independently and it is therefore presented, as it was written, in two parts.

PART 1. AMBLYGONITE FROM HEBRON, MAINE

W. E. Richmond and C. W. Wolfe

About five years ago the late W. D. Nevel of Andover, Maine, discovered a small pocket in the lithium pegmatite which he was working at Hebron. The walls of the cavity, consisting of quartz and microcline, were thickly encrusted with tiny sharp-pointed, white crystals whose identity remained unknown to Mr. Nevel and was established as amblygonite by Richmond. The entire contents of the cavity in the form of about twenty small fragments of the wall-rock coated with the crystals, were secured for the Harvard Collection in 1938 and bears the single catalogue number 94819.

The crystals of amblygonite are white, translucent to transparent, and vary in size from one-half to three millimeters in the direction of elongation [010]. They are generally attached to the matrix by one end of this *b*-axis and are of two types, although all prove to be twin crystals. The types differ chiefly in the degree of their tabular development, which is illustrated in the drawings (Figs. 1 and 2). In one they are thin-tabular parallel to the plane of composition of the twins $\{\bar{1}\bar{1}1\}$, and the individuals are either exactly symmetrical to this plane or approximately so. In the other type the flattening is parallel to the prism {110} and the two individuals are of very unequal size. The two types are intermingled on the surfaces where they occur with no apparent difference in age. The faces of these tiny crystals are for the most part brilliant and plane, giving excellent reflections on the goniometer. But there are delicate striations in the prism zone [001], and one form is characteristically curved as described below.

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* Contribution from the Department of Mineralogy and Petrography, Harvard University, No. 257.

Orientation of Amblygonite. Des Cloizeaux (1863) gave the first crystallographic setting based on measurements of cleavage only. He assigned the three cleavages which he found to *p*{001}, *m*$\{1\bar{1}0\}$, and *t*{110}. He established the presence of lamellar twinning in two directions, to which he assigned the symbols *L*{111} and *H*$\{\bar{1}11\}$. It may be worthy of note that the diagrammatic figure in Dana's *System* (Fig. 2) "after *Dx*" shows two cleavages and a large face *s*, which is an arbitrarily cut surface and not a cleavage. Des Cloizeaux wrote several papers on the mineral but seems never to have had crystals with determinable form. Groth (1889) and Goldschmidt (1886) retained this orientation, but the latter assigned different letters to the cleavage forms.

J. D. Dana (1873) seems to have been the first to measure a crystal of amblygonite. E. S. Dana (1892) remeasured this rough but definite crystal which came from Hebron, and from his contact measurements established the elements and forms which have been accepted since then by all authors. The elements are of necessity but first approximations to accurate values, a fact which should have been indicated by expressing them in terms of two places of decimals and the angles in whole degrees rather than in five place of decimals and fractions of a minute as Dana did. Later contributions to the morphology of amblygonite have been few. Schaller (1916) measured by contact rough crystals of sodium-rich members of the series upon which he found, besides forms already known, the side pinacoid {010}. Quensel (1937) and Tenger (1940) described the amblygonite of Värutrask, Sweden, on which the side pinacoid was also found as well as the additional new form $\{0\bar{1}1\}$. These writers employed Dana's position and elements.

To avoid confusion, new letters have been assigned to all the forms.

The transformation formulae leading to the correlations of Table 1 are as follows:

Des Cloizeaux to Dana	$200/\bar{1}\bar{1}0/002$
Des Cloizeaux to Richmond and Wolfe	$002/\bar{1}\bar{1}2/200$
Dana to Richmond and Wolfe	$001/011/100$

TABLE 1. AMBLYGONITE: CORRELATION OF SETTINGS

Richmond	Cleav.	Des-cloizeaux	Cleav.	Dana	Cleav.
c 001	Imperf.	*m* $1\bar{1}0$	best	*a* 100	Less perf. than *c*
**b* 010		—		—	
a 100	Perf.	*i*	3d best	—	Not given
w 110	Good	*p* 001	2d best	*c* 001	Perf.
W $1\bar{1}0$	None	—		*e* $0\bar{2}1$	"As good as *a* sometimes"
o 011		—		*m* 110	
d $0\bar{1}1$	Distinct	*t* 110	bad	*M* $1\bar{1}0$	Difficult
u $0\bar{2}1$		—		*z* $1\bar{2}0$	
r 111		*L* $1\bar{1}1$	(Twin.)	*l* 101	As twin plane
t $\bar{1}11$		*H* $\bar{1}11$	(Twin.)	*h* $\bar{1}01$	As twin plane
**s* $\bar{1}21$		—		—	

* Denotes new form.

The results of our x-ray cell determination require a new orientation to satisfy the conventional rules for the triclinic system. It proved that Dana's elements, transformed to the new position, were very similar to the new elements derived from the x-ray and morphological studies.

X-Ray Lattice Constants. The crystal used in the determination of the lattice constants was the smaller individual of a twin. This crystal was colorless and flawless, exhibited no evidence of twinning under the microscope, and was 0.25 mm. in its greatest dimension. Rotation, zero and first-layer line Weissenberg photographs were taken about three zone axes, which proved to be the three shortest non-coplanar identity periods and therefore the crystallographic axes.

The measured and calculated values obtained from these photographs are summarized as follows:

$$a_0=5.18,\ b_0=7.11,\ c_0=5.03\text{Å}$$

$$a_0:b_0:c_0=0.729:1:0.709;\quad \alpha=112°02\tfrac{1}{2}';\quad \beta=97°49\tfrac{1}{2}';\quad \gamma=\ 68°07\tfrac{1}{2}'$$

$$a^*:b^*:c^*=0.970:0.755:1;\quad \alpha^*=69°19\tfrac{1}{2}';\quad \beta^*=90°14\tfrac{1}{2}';\quad \gamma^*=110°29\tfrac{1}{2}'$$

These constants agree closely with the morphological elements (Table 3).

Crystal Measurements. Some thirty crystals from Hebron were measured in two positions on the two-circle goniometer. At first, before the best setting had been determined, crystals were set up with the dominant zone containing the twin plane vertical. This proved to be equivalent to Dana's setting in second permutation, that is with the zone [010] Dana, [011] Richmond, vertical.

The proper orientation having been determined by the x-ray study, the crystals were remeasured in the chosen position with the results summarized in Table 2. The observed angles of the forms marked with an asterisk in that table constituted the basis for calculation of new elements which are shown in Table 3, together with the angles calculated from them for the various known forms shown in Table 1.

TABLE 2. AMBLYGONITE: SUMMARY OF MEASURED AND CALCULATED ANGLES

Form	No. Faces	Measured Range		Weighted Mean		Calculated	
		ϕ	ρ	ϕ	ρ	ϕ	ρ
**c* 001	60	19°28′– 19°58′	21°25′–22°08′	19°46½′	21°59′	19°46½′	21°59′
b 010	8	359 22 – 0 56	90°00′	0 10	90 00	0 00	90 00
**a* 100	60	110 12 – 110 29	90 00	110 21	90 00	110 21	90 00
w 110	42	65 21 – 65 38	90 00	65 28	90 00	65 30	90 00
W $\bar{1}10$	28	139 48 – 140 22	90 00	139 58	90 00	140 08	90 00
o 011	1	6° 38′	50 42	6 38	50 42	6 33½	50 06
**d* $0\bar{1}1$	60	162 13 – 162 24	24 08 –24 20	162 19	24 12½	162 19	24 12½
**t* $\bar{1}11$	60	−94 20 – −94 34	39 52 –40 15	−94 28½	40 09	−94 28½	40 09
s $\bar{1}21$	16	−135 22 – −136 58	49 21 –51 18	−135 43	50 01	−136 06	50 30

* Fundamental angles used for calculation.
b an *s* are new forms.

TABLE 3. AMBLYGONITE: ANGLE-TABLE

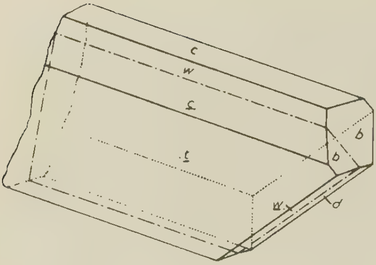
Amblygonite—(Li, Na)$AlPO_4(OH,F)$
Triclinic: pinacoidal—$\bar{1}$
$a:b:c=0.7255:1:0.7028$; $\alpha=111°59½'$; $\beta=97°46½'$; $\gamma=68°16½'$
$p_0:q_0:r_0=0.9669:0.7495:1$; $\lambda=69°22'$; $\mu=90°13'$; $\nu=110°21'$
$p_0'=1.0427$, $q_0'=0.8083$; $x_0'=0.1366$, $y_0'=0.3800$

Forms		ϕ	ρ	A	B	C
c	001	19°46½′	21°59′	90°13′	69°22′	—
**b*	010	0 00	90 00	110 21	—	69°22′
a	100	110 21	90 00	—	110 21	90 13
***Z*	120	37 56½	90 00	72 24½	37 56½	69 13
w	110	65 30	90 00	44 51	65 30	74 51
W	$1\bar{1}0$	140 08	90 00	29 47½	140 08	100 54½
o	011	6 33½	50 06	100 32	40 21	29 01½
***q*	021	3 55	63 27	104 40	26 49	42 33
d	$0\bar{1}1$	162 19	24 12½	75 22	112 59½	43 37½
u	$0\bar{2}1$	173 42	51 12½	69 32½	140 46½	71 24½
r	111	53 27½	54 12½	63 42	61 07	37 20½
***f*	$\bar{2}\bar{2}3$	− 80 51½	27 33	116 59	85 47	37 48
t	$\bar{1}\bar{1}1$	− 94 28½	40 09	125 49½	92 53	52 26½
***v*	$\bar{3}\bar{3}2$	−102 14½	53 41½	132 46½	99 50½	67 05½
**s*	$\bar{1}21$	−136 06	50 30	108 00	123 47	70 57½
***g*	$\bar{1}\bar{2}2$	−125 02½	23 16½	102 58	103 07	43 02
***k*	$\bar{3}\bar{5}2$	−129 31	59 53	115 44	123 23½	79 13½
***x*	$\bar{2}\bar{3}1$	−125 58	66 00½	120 26½	122 27	84 35
***i*	$\bar{5}\bar{7}2$	−123 46	70 11	123 28½	121 31½	88 13½

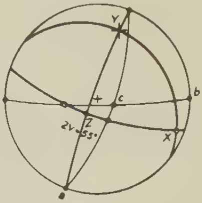
* New forms (Richmond & Wolfe).
** New forms (Palache).

The elements of Dana recalculated to the new position by means of the transformation matrix Dana to Richmond = 001/011/100 are as follows and show close agreement with the new elements:

$$a:b:c=0.7314:1:0.7027$$
$$\alpha=111°45',\ \beta=97°48½',\ \gamma=65°03½'$$



1



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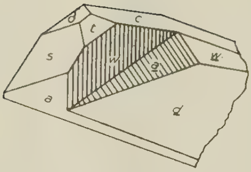

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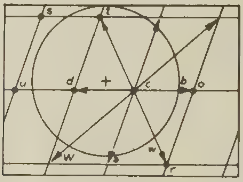

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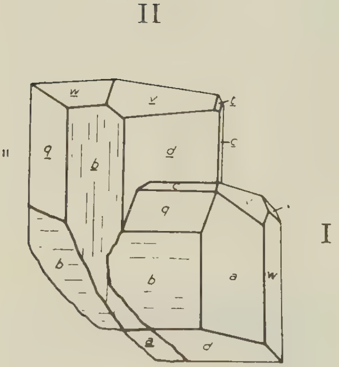

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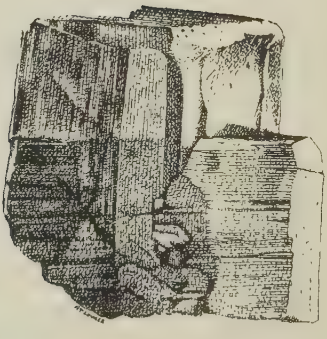


8

FIG. 1. Amblygonite, Hebron. Twin crystal of type 1. Axonometric projection.

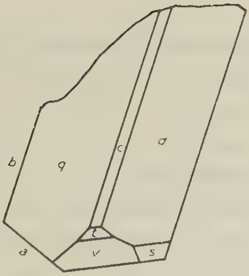
FIG. 2. Amblygonite, Hebron. Twin crystal of type 2. Axonometric projection, viewpoint at the back.

FIG. 3. Amblygonite. Gnomonic projection of crystal forms.

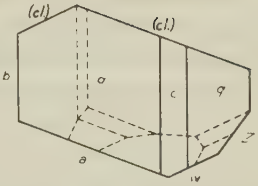
FIG. 4. Amblygonite. Optical orientation in stereographic projection.

FIG. 8. Amblygonite twin crystal, Newry. Same as No. 9. A drawing by A. T. Lougee from about the viewpoint of Fig. 9.

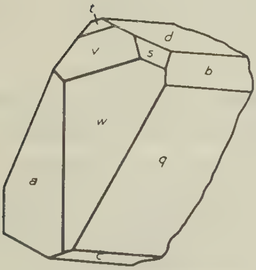
FIG. 9. Amblygonite twin crystal, Newry. Harvard University No. 95852. Axonometric projection, viewpoint at the right and behind a normal to the side pinacoid.



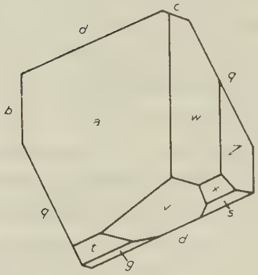
5a



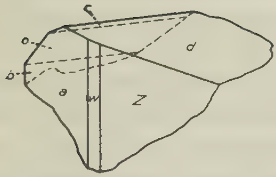
7a



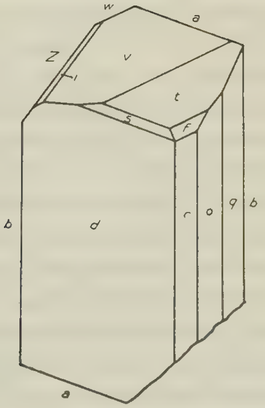
5b



7b



10



6

Fig. 5*a*. Amblygonite, Newry. Crystal of Mr. Ford. Orthographic projection normal to the prism zone (back to front). 5*b*. Axonometric projection, viewpoint at the back.

Fig. 6. Amblygonite, Newry, Harvard University No. 97058. Orthographic projection normal to prism zone.

Fig. 7. Amblygonite, Newry. Crystal of Brush Collection. Orthographic projection. *a*. Plan. *b*. Elevation.

Fig. 10. Amblygonite, Newry. Crystal of Mr. Bjareby. Axonometric projection, viewpoint at the back.

The new form $s\{\bar{1}\bar{2}1\}$ was seen only on crystals of type 2. It is always present as a large curved plane, showing evidence of solution. The reflections were very unsatisfactory, and only on two crystals were sufficiently good signals obtained to identify the form.

The form $b\{010\}$, which has previously been found only by Quensel (1937) is confined to crystals of type 1. It was measured on eight crystals and varied from a point of light barely visible on the goniometer to a well-formed plane face. It was generally coated with a film of sericite which, however, could be removed with a sharp blade; the face then gave adequate signals. Typical development is shown in Fig. 1.

Figure 3 shows the forms of Table 1 in gnomonic projection in the new orientation.

Twinning. As already stated, the crystals are always twinned. The twin law is that originally announced by Des Cloizeaux with twin and composition plane $t(\bar{1}\bar{1}1)$. The index, 1, of this twin and the obliquity, about $1\frac{3}{4}°$, indicate the probable frequency of the twinning according to this law. The twin law $r(111)$, also described by Des Cloizeaux as twin lamellae, has an index of 1 and an obliquity of about $3\frac{1}{2}°$, which perhaps explains the rarity of this twinning as compared with the former law.

Cleavage of Amblygonite. Dana gives four cleavages for amblygonite, which are entered in Table 1 after the forms. In the Richmond column are entered the cleavages determined with exactness on the Newry crystals to be later described. It will be seen that they agree except for Dana's cleavage $(0\bar{2}1)$. There is no cleavage on $W(1\bar{1}0)$, Richmond's equivalent to this form. On the other hand, the perfect cleavage on (100) Richmond, which would be $(0\bar{1}1)$ in Dana position, is not represented among Dana's cleavages. We believe that Dana's cleavage $(0\bar{2}1)$ should have been reported as $(0\bar{1}1)$. Quensel (1937) reports this form but says nothing about cleavage parallel to it.

Optics. The indices of refraction of amblygonite were obtained on small grains by the immersion method and are not materially different from those already published (Larsen and Berman, 1925).

The optical orientation was determined on a small untwinned crystal which was mounted on the universal stage. The observed data are summarized in Table 4. The optical orientation and the positions of the optic axes, as referred to the principal crystallographic planes, are shown stereographically in Figure 4.

TABLE 4. OPTICAL ORIENTATION OF AMBLYGONITE

	ϕ	ρ	
X	$19\frac{1}{2}°$	83°	Positive
Y	$-72\frac{1}{2}°$	69°	$2V = 55° \pm 2°$
Z	130°	21°	

Unit Cell. In the following table is given an analysis by Penfield of amblygonite from Hebron. From this analysis and a newly determined specific gravity on the crystals described, the unit cell contents are given in the last column. The unit cell of amblygonite contains 2[$LiAlPO_4(OH,F)$]; in the analysis of the table OH:F$\sim$2:1.

TABLE 5. CONTENT OF THE UNIT CELL OF AMBLYGONITE

	1	2	3	4		5	
Al_2O_3	33.90	34.01	0.334	Al	0.668	1.97	2
Li_2O	9.24	9.29	0.310	Li	0.642	1.89	2
Na_2O	0.66	0.66	0.011				
P_2O_5	47.44	47.60	0.335	P	0.670	1.97	2
H_2O	5.05	5.06	0.282	H	0.564	1.66	2
F	5.45	5.47	0.287	F	0.287	.84	
	101.74	102.09		O	3.150	9.27	10
Less O for F	2.08	2.09					
	99.66	100.00					

1. Amblygonite, Hebron. Penfield, anal. (Anal. No. 6 in Dana, p. 782.)
2. Computed to 100%.
3. Molecular proportions.
4. Atomic proportions.
5. Number of atoms in unit cell, using molecular weight of 294.11 (derived from cell volume of 159.11Å^3 and specific gravity 3.05 as newly determined on the crystals).

PART 2. AMBLYGONITE FROM NEWRY, MAINE

CHARLES PALACHE

Crystals of amblygonite of really spectacular quality were found during 1940 and 1941 in a new pit opened for feldspar on Newry Mountain about two hundred yards east of the old Nevel pollucite quarry. The crystals are found in pockets in the pegmatite up to about two feet square and are attached to the feldspar walls. With them, besides quartz and beryl, have been found small amounts of triphyllite, apatite of pale violet color, small amounts of eosphorite, cassiterite, and rhodochrosite. The identification of the mineral as amblygonite was first made by Mr. M. E. Bailey of Andover, Maine. Through him and Mr. F. D. McAllister of the same place, and through Mr. E. F. Miller of Rumford Point, the Superintendent of the quarry, the writer has been able to examine a considerable number of crystals, and the Harvard Mineralogical Museum has acquired two of the better specimens. A third crystal of equal quality has been loaned by the Brush Collection of Yale University through Dr. George Switzer. A fourth crystal was loaned by Mr. H. A. Ford of Boston. The following description is based chiefly on the four largest and finest crystals; other smaller ones have also been loaned for examination and have yielded valuable measurements. The writer's thanks are gratefully extended to the numerous collectors who have thus made it possible to secure a representative series of specimens of this new and unprecedented find.

The crystal of Mr. Ford, the largest of the four, is a nearly flat slab measuring 11 by 8.5 cm. and 4 cm. thick. As shown in Fig. 5 *a* and *b*, the dominant zone is parallel to the *a*-axis. The largest planes are the two faces of *q*{021}, which are further characterized by the more or less uniform coating of brownish eosphorite which renders them entirely matte. The forms *d*, *a*, and *w* are glassy and brilliant, in marked contrast to the faces of *q*.

The crystal secured from Mr. Bailey (No. 97058) is the second largest of the four, measuring about 7 by 5.5 by 4 cm. It is doubly terminated in respect to the *a*-axis but shows cleavage and contact surfaces on one end and side. It is shown in its true proportions in Fig. 6.

The Yale crystal is only slightly smaller, measuring 6 by 5 by 4 cm. It is doubly terminated on the *c*-axis and is bounded on the back by a clean cleavage break. Figure 7 *a* and *b* reproduces it. Both these crystals are greenish yellow in color, transparent in part though with many flaws, and have for the most part brilliant reflecting faces although, as will be shown, some of the bounding forms are consistently dull. If one were to seek for a familiar mineral to which to compare their appearance one might think of the larger Westfield datolites, perhaps. But no close comparison occurs to the writer.

The second Harvard specimen (No. 95852) is a twin crystal, the two individuals quite distinct in their upper portions, interpenetrating in their lower parts. The pen-and-ink drawing by A. T. Lougee, reproduced in Fig. 8, gives an excellent idea of the specimen. The reproduction is nearly natural size, the group having a maximum (diagonal) diameter of 6 cm. and a thickness of 2.5 cm. No one, however familiar he might be with the ordinary macroscopic crystals of amblygonite which are opaque and have faces devoid of luster, could possibly suspect the nature of this crystal. It looks more like a large specimen of twin adularia from Switzerland than any other familiar mineral. The terminal portions of both components of the twin are clear and almost colorless, the basal portions slightly opaque and of faintly yellowish color. Most of the faces are plane and brilliantly reflecting, only the side pinacoids and one brachydome being matte so that they could only be measured by attaching slips of glass to their surfaces. The drawing shows well how these latter faces are striated and how the lineation due to this stands in the two individuals almost at right angles. It also brings out the apparent coplanar relation of the pinacoids on the two portions of the twin. The principal elongation of both individuals is in the direction of the brachyaxis as best shown in Fig. 9.

The removal of the crystal group from the matrix to which it must have been attached by its basal portion developed many cleavage planes of high perfection. Study of these together with contact measurements enabled the nature of the forms and the probable twin law to be worked out approximately by inspection. However, it was found possible to mount the unwieldy crystal on the two-circle goniometer. Reflections were satisfactory, but of course the measurements were less exact than would have been the case from a smaller crystal owing to the long traverses needful to bring different parts of the crystal, especially of the twin, into reflection. The three larger crystals could only be measured with the contact goniometer, but by using the measurements of the twin their forms could be established with reasonable certainty.

The crystal was set on the goniometer with individual I in normal position, that is with its prism zone vertical; individual II in twin position has its prism zone almost horizontal. Figure 9 is a clinographic projection from a point of view well behind the *b*-axis while the sketch, Fig. 8, is taken from about the same point of view but more nearly normal to *b*.

The nature of the intergrowth is such that neither member of the twin shows any faces in front of the brachydome zone [100]. Both members were measured with the same setting on the goniometer. Table 6 containing the measurements is, however, divided into two parts somewhat differently arranged, each containing the faces of one individual.

TABLE 6. MEASUREMENTS OF AMBLYGONITE TWIN

a. Individual I in normal position

		Measured		Calculated	
		ϕ	ρ	ϕ	ρ
b	010	0°53′	90°00′	0°00′	90°00′
b′	$0\bar{1}0$	180 00	90 00	180 00	90 00
c	001	18 25	22 20	19 46½	21 59
a′	$\bar{1}00$	− 69 52	90 00	− 69 39	90 00
w′	$\bar{1}\bar{1}0$	−114 50	90 00	−114 30	90 00
d	$0\bar{1}1$	161 13	23 51	162 19	24 12½
**q*	021	3 50	64 28	3 55	63 27
**v*	$\bar{3}\bar{3}2$	−102 18	53 45	−102 14½	53 41½
**x*	$\bar{2}\bar{3}1$	−126 25	65 00	−125 58	66 00½

b. Individual II in twin position

		Measured		Calculated (approx.)		Nearest face in normal position			
		ϕ	ρ	ϕ	ρ			ϕ	ρ
c	001	−114°25′	89°10′	−114°30′	89°44′	*w*	$\bar{1}\bar{1}0$	−114°30′	90°00′
b	010	not measured		0 00	87 00	*b*	010	0 00	90 00
a	100	154 55	26 05	155 15	27 00	*d*	$0\bar{1}1$	162 19	24 12½
w	110	12 45	22 35	20 02	22 00	*c*	001	19 46½	21 59
d	$0\bar{1}1$	− 70 45	86 40	− 71 30	87 00	*a′*	$\bar{1}00$	− 69 49	90 00
t	$\bar{1}\bar{1}1$	− 94 16	40 13	− 94 28½	40 09	*t*	$\bar{1}\bar{1}1$	− 94 28½	40 09
v	$\bar{3}32$	− 80 55	28 00	− 79 30	28 00	none near			

Examination of the first part of Table 6 shows good agreement between measured and calculated position angles both for the known forms and the three new forms marked with asterisk. No face of the form *t*{$\bar{1}\bar{1}1$} was found on the normal individual because the corner where it might have occurred was chipped away.

The second group of angles in part *b* of Table 6 requires explanation. It was secured by plotting the normal forms on a stereographic projection of 20 cm. diameter, and then introducing the same forms in twin position. The position angles of these forms in twin position could then be read off with an accuracy of about one-half degree. The considerable labor of accurate calculation of these positions seemed disproportionate to its value.

The determination of the twin plane is established by the fact that *t*{$\bar{1}\bar{1}1$} on the twin crystal falls exactly in the calculated position of this form in normal position. This form is the equivalent in Richmond's new setting of Des Cloizeaux's plane of lamellar twinning, *H*{$\bar{1}\bar{1}1$}.

From the third column of Table 6 it is seen that important forms fall in twin position very near to normal forms. Most noteworthy of these coincidences are *c*{001} with *w*{110} twinned and *a*{100} with *d*{001} twinned. These four forms all have cleavage of varying degrees of perfection as shown in Table 1; and the near coincidence of these unlike cleavages, seen wherever a fracture plane crossed the boundary between the two individuals, is good proof of the correctness of the various form determinations of Table 6 and of the identity of the plane of twinning.

Further measurements were secured on six crystals, for the most part small and of poor quality, which are contained in Table 7.

TABLE 7. MEASUREMENTS OF SIX CRYSTALS OF AMBLYGONITE

		No.	Qual.	Mean		Range	
				ϕ	ρ	ϕ	ρ
c	001	5	fair	19°28′	21°43′	18°35′– 21°07′	19°40′–22°44′
a	100	10	good	110 23	90 00	109 48 –111 00	— —
b	010	4	v. poor	0 04	90 00	0 00 – 0 12	— —
w	110	7	fair	65 13	90 00	63 19 – 66 28	— —
o	011	1	poor	5 18	49 23	—	—
d	$0\bar{1}1$	3	good	162 16	24 23	162 12 –162 18	24 19 –24 30
t	$\bar{1}\bar{1}1$	4	fair	– 93 34	40 22	92 12 – 94 34	40 09 -41 15
**g*	$\bar{1}\bar{2}2$	1	v. poor	–117 53	21 10	—	—
**f*	$\bar{2}\bar{2}3$	1	v. poor	– 79 19	28 30	—	—
**v*	$\bar{3}\bar{3}2$	1	good	–102 13	53 50	—	—
**k*	$\bar{3}\bar{5}2$	1	poor	–130 40	60 00	—	—
**i*	$\bar{5}\bar{7}2$	1	v. poor	–123 39	70 00	—	—

Contact measurements for some of these forms and for the three new forms for which no position angles were obtained will be found in the description of the individual forms which follows.

Characteristics of the forms.

c{001} is always present and always brilliant. It varies from a line face to one of considerable breadth.

b{010} is always present and sometimes dominant. It is always completely matte and is generally striated in [100].

a{100} is present on all crystals and is generally the largest face in the prism zone. It is brilliant, usually smooth, and shows a pearly luster owing to the perfect cleavage parallel to it. It is separated from the prism {110} on several crystals by a striated area which sometimes forms a shallow groove.

w{110} is also always present and usually constitutes with the two preceding forms the prismatic zone. It is always bright and of high luster but may be vertically striated over part of its area, or show slight unevenness.

**Z*{120}. This new prism is developed as a broad, matte face on the two large crystals shown in Figs. 6 and 7. It was determined by contact measurement. $bZ = \phi = 37°\ 30'$, Cal.$\phi = 37°\ 56\frac{1}{2}'$.

o{011} was seen twice as a long and narrow, matte face on both top and bottom of the crystal of Fig. 6. Established by a contact measurement $co = 30°$, Cal. $C = 29°\ 01'$. One position angle was also obtained for it (Table 6).

d{$0\bar{1}1$} is one of the largest and most brilliant faces on every crystal. It is sometimes, however, etched over part of its surface.

q{021} is a new brachydome found on nearly every crystal and largely developed as shown in the figures. However, it is always matte and was determined by contact measurement. $cq = 43°$, Cal. $C = 42°\ 33'$. On the twin crystal, Table 5, one position angle was obtained by use of a glass slip attached to it.

t$\{\bar{1}\bar{1}1\}$ is a brilliant face, always present, varying from a narrow line to a broad surface. On most twin crystals its simultaneous reflection on the two individuals identifies it at once.

**g*$\{\bar{1}\bar{2}2\}$. This new pyramid occurs as a narrow, matte face truncating the edge *dt*. Measured (mean of 2) $d\text{-}g=27°\ 30'$, Cal. $27°\ 36'$. It was further established by one position angle, shown in Table 7.

**f*$\{\bar{2}\bar{2}3\}$. This new form is seen on several crystals truncating the edge *ct* but too narrow for satisfactory contact measurement. One position angle is given for it in Table 7.

**v*$\{\bar{3}\bar{3}2\}$. This new pyramid is one of the important forms in the development of every crystal. It is often the largest terminal face except *d*, is frequently bright, and was determined by measurement on the twin crystal as shown in Table 6. Again it may be quite dull and striated lightly parallel to its intersection with *c* and *t* in the zone $[\bar{1}10]$.

**k*$\{\bar{3}\bar{5}2\}$. This new pyramid was seen twice as a narrow truncation of the edge *bv*. Contact measurement $vk=23°$, Cal. $23°\ 33'$. One good position angle is also shown in Table 7.

**x*$\{\bar{2}\bar{3}1\}$. A new pyramid established by its measurement on the twin, Table 6. It was checked by contact measurements. $a\text{-}x=120°$, $A=120°\ 20'$; $b\text{-}x=123°$, $B=122°\ 27'$.

s$\{\bar{1}\bar{2}1\}$. This pyramid was found but once, on the Yale crystal, Fig. 7. Established by contact measurements $a\text{-}s=110°$, Cal. $A=108°\ 00'$; $b\text{-}s=125°$, Cal. $B=123°\ 47'$. On this crystal the forms *v*, *x*, and *s* merge in a curved surface not shown in the drawing. A similar curvature is present but not figured on the twin crystal.

**i*$\{\bar{5}\bar{7}2\}$. This new and weak form was seen twice truncating the edge *sk*. One position angle for it is shown in Table 7. It was measured once by contact on the edge between $v(\bar{3}\bar{3}2)$ and $Z(\bar{1}\bar{2}0)$. $v\text{-}i=27°$, Cal. $25°\ 02'$. Thus it is established as lying in two zones.

Examination of Tables 6 and 7 in comparison with Table 3 will show that all the forms listed for amblygonite from Hebron by Richmond and Wolfe have been found on Newry crystals except $W\{1\bar{1}0\}$. In addition, eight forms new to the species have been found, the angles for which have been calculated on their elements and are presented in Table 3.

Twinning. Of the seventeen crystals which were examined in this study, five proved to be twinned, always according to the same law as found on the Hebron crystals, twin plane $(\bar{1}\bar{1}1)$. The development of twinning is extremely varied. The twin described at length and figured was the only one seen which presented clearly separated individuals. Two others nearly as large were seen, but they had imperfect faces or cleavage surfaces. In both there was more complete intergrowth of the two individuals, somewhat in the nature of a "graphic" structure, so that small points of one individual projected from larger surfaces of the other. In one crystal there were three small inserts visible in the base of the crystal, parallel to one another as far as could be seen, and in twin relation to the main crystal.

Amblygonite of an entirely different quality from the crystals described above is represented by a specimen found at the Newry Quarry by Mr. Gunnar Bjareby and loaned to the writer for study. The specimen consists of a crystal fragment measuring about 8 by 6 by 4.5 cm. which occurred embedded in feldspar from which it had been partially freed. It is white and opaque with plane but entirely matte faces. The general form is that of a nearly square pyramid with two edges truncated by narrow faces. Contact measurements and the study of the cleavage finally established the forms present to be as shown in Fig. 10, all of which are known on the better crystals. The specimen is very similar in appearance to feldspar and might easily be mistaken for it.

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NOTES AND NEWS

MAKING CRYSTAL MODELS

D. Jerome Fisher, *University of Chicago, Chicago, Illinois.*

Under the above title the writer described a method of preparing a net from the gnomonogram to make hollow models of crystals out of Bristol board, etc.[1] In this paper the procedure given for obtaining the lengths of the various edges was primarily the type of projection involved in descriptive geometry.[2] An alternative method which students find simpler in actual practice is as follows.

The length of any edge Ln in the pattern (net) drawing may be derived from the length of the corresponding edge Lp in the plan drawing. Carefully measure the latter value for a given edge. Then in the gnomonogram connect the face-poles of the two faces making the edge in question by a line, which may be called a zone-line. With a straight edge placed along this line, by means of a right-angle triangle erect a normal to this zone-line through the center O of the primitive circle, giving the zone central ZO (where Z the zone center is at the junction of the two lines). Measure the value of OZ in gnomonic degrees with the projection protractor. Call the result ρ_z, the angle of dip of the edge in question (c-axis vertical). Then

$$Ln = \frac{Lp}{\cos \rho_z}.$$

This equation may be solved easily with the slide rule if it is recalled that $\sin A = \cos (90° - A)$ so that the above equation becomes

$$Ln = \frac{Lp}{\sin (90° - \rho_z)}.$$

Thus using the A and S scales proceed as follows:

read upwards	Scale A	to Lp	read Ln
	Scale S	Set $(90° - \rho_z)$	at 90°

That is, put the cursor at Lp on the A scale; slide the S scale till $(90° - \rho_z)$ lies under the cursor. Now move the cursor along till it lies above 90° on the S scale, and read the answer $(= Ln)$ where the cursor cuts the A scale.

In the original paper the caption "Figure 5" should be added below the perspective drawing on p. 725 (*Am. Mineral.*, **26**, 1941).

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[1] *Am. Mineral.*, **26**, 718–726 (1941).

[2] *Op. cit.*, pp. 721–724, especially p. 723.

ALUMINUM-BEARING SCORODITE FROM HOBART BUTTE, OREGON

REYNOLDS M. DENNING, *Stanford University, California.*

Hobart Butte is located in Lane County, Oregon, about two and a half miles northwest of Blackbutte Mine Postoffice. The upper part of the hill is composed largely of an altered andesite tuff, which is quarried for the clay it contains. It is in this quarry that the scorodite is found. The mineral occurs in zones that are very suggestive of old hot spring channels.[1]

The andesite tuff is quite thoroughly altered to a fine material with low birefringence. Some unaltered glass is present. This glass contains very cloudy, brown incipient spherulites of feldspar (?), which are white in reflected light.

Small amounts of realgar were found in the quarry, but not in close association with the scorodite.

Megascopic description

In the hand specimen the scorodite is light green in color, has a high vitreous luster, occurs in colloform crusts, and shows an open cellular structure. Except for color and luster, the mineral closely resembles geyserite opal. Iron stains accompany the scorodite in some specimens.

Optical tests

In thin section the scorodite appears in colloform crusts up to 1.5 mm. thick, coating the glass and altered tuff. It is colorless, has a high relief in balsam and indices of refraction greater than the balsam. It shows an aggregate structure with spherulites and axiolites that closely resemble some types of chalcedony. Sections of normal thickness show lower second order interference colors. The birefringence determined in sections containing quartz is about 0.020. The fibers are length slow. The accompanying figure shows the appearance of the mineral in thin section.

The indices of refraction were found to be: $n_\alpha = 1.712$, $n_\gamma = 1.728$. Because of the difficulty of orientation n_β was not determined. The indices were measured as follows: The crushed fragments of clear scorodite were placed in methylene iodide. The grains were then examined in sodium light and α-monobromnaphthalene slowly added until the grains showing the highest index of refraction matched the oil. The index of refraction of the oil was then determined by using a hollow prism and the minimum deviation method. The procedure was then repeated for the lowest index. The maximum error in this measurement is ±0.003. The birefringence thus obtained agrees within the limits of error found in thin sections containing quartz.

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[1] Hague, James Duncan, Notes on the deposition of scorodite from arsenical waters in the Yellowstone National Park: *Am. Jour. Sci.* (3), **34,** 171–175 (1887).

Spectrographic and chemical tests

For a chemical examination about 2 grams of scorodite were roughly hand picked under a binocular microscope and crushed. It was then screened; the minus 80 plus 60 material was then separated with acetylene tetrabromide to remove the clay and other impurities. The product of this separation was then again hand picked to obtain as pure a sample as possible for spectrographic analysis.

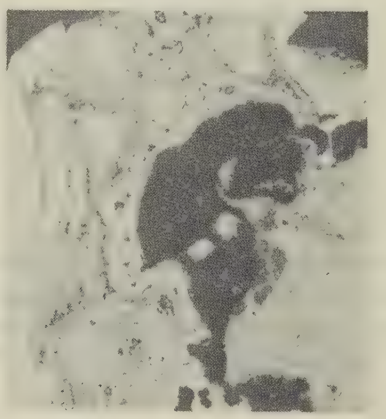

FIG. 1. Colloform crust of aluminum-bearing scorodite on iron-stained altered tuff. About 15×. Plane polarized light.

A spectrum covering the region from 2800 to 3400 Å was made on a 21-foot concave grating instrument. The elements iron, arsenic, and aluminum were found to be present in considerable abundance. No other lines were noted on the film.

Heated alone in a closed tube, the mineral yields abundant water. In a closed tube with charcoal, a good arsenic mirror is formed. On charcoal, the material fuses to a black magnetic globule.

The mineral, unlike most scorodite, is not completely soluble in HCl or HNO_3. It is decomposed by these acids, leaving a white residue. When the HCl solution is made ammoniacal, a brown precipitate is formed. When this precipitate is treated with KOH, the solution acidified with HCl and again made ammoniacal, a slight white precipitate is produced. These tests show the presence of iron and some aluminum. If the material is first fused with $NaPO_3$, a stronger aluminum test is obtained. After the precipitation of iron and aluminum, arsenic is readily precipitated by H_2S. After this separation, a test was made for the phosphate radical, but none was found.

The ammonium paramolybdate microchemical test for arsenic gives excellent results with a nitric acid solution of the mineral. Ammonium chloride gives a good microchemical iron test.[2]

Summary and conclusions

The above spectrographic and chemical tests indicate a mineral containing iron, arsenic, aluminum, and water. Except for the aluminum, the mineral contains the same elements as in scorodite. The indices of refraction and birefringence are somewhat lower than those given for scorodite. The simplest explanation seems to be that the mineral under investigation is an aluminum-bearing scorodite. Isomorphism of aluminum and iron is not unusual, although it has not been reported in scorodite.

The approximate composition was estimated by means of Gladstone and Dale's Law.[3] This was done by computing the theoretical mean index of refraction of $Fe_2O_3 \cdot As_2O_5 \cdot 4\ H_2O$ (scorodite) and $Al_2O_3 \cdot As_2O_5 \cdot 4\ H_2O$ (hypothetical compound), and comparing these values with the mean index for the mineral under investigation. The values of n for these compounds were computed to be:

Scorodite (iron end member)	1.784
Mineral under investigation	1.720
Hypothetical aluminum end member	1.577

Since n_β was not determined, the mean index of the mineral under study was taken as $\sqrt{n_\alpha n_\gamma}$ instead of $\sqrt[3]{n_\alpha n_\beta n_\gamma}$, a close approximation. The ratio of the iron member to the hypothetical aluminum member of the series was found to be 2.23:1.

The percentage composition of this aluminum-bearing scorodite was calculated, by this method, to be:

Fe_2O_3	24.9 per cent
Al_2O_3	7.1 per cent
As_2O_5	51.8 per cent
H_2O	16.2 per cent

This, of course, must be regarded only as a rough approximation.

The writer wishes to thank Dr. Austin F. Rogers and Dr. A. C. Waters of Stanford University for much valuable assistance in the preparation of this note.

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[2] Staples, Lloyd W., Mineral determination by microchemical methods: *Am. Mineral.*, **21**, 613-634 (1936).

[3] Larsen, Esper S., and Berman, Harry, The Microscopic Determination of The Nonopaque Minerals, *U. S. Geol. Survey, Bull.*, **848**, 30-32 (1934).

BOOK REVIEWS

DIE MINERALIEN DER SCHWEIZERALPEN by P. NIGGLI, J. KOENIGSBERGER and R. L. PARKER, with the collaboration of O. GRÜTTER, F. DE QUERVAIN, F. N. ASHCROFT and F. WEBER. In two volumes: Pp. 661, Pl. 20, Figs. 251. B. Wepf & Co., Basel, **1940**. Price 24 Swiss francs.

Doubtless every reviewer feels that the few paragraphs to which he is usually limited are wholly inadequate to present his subject. That is particularly true in the present instance, so packed with riches are these two volumes. Indeed, even to reproduce the tables of contents would occupy more pages than can be allocated to a book review. Perhaps, therefore, the purpose of this review will be served if it no more than calls attention to the existence of this treasure-house, rather than attempting a detailed digest and concentrate of its rich contents.

The beautifully crystallized transparent quartz crystals from alpine "clefts"[1] were known to the ancient Greeks and from this "ice-stone" has sprung not only the name but much of the science of crystallography. Crystals of quartz, adularia, and many other minerals from these localities are represented in collections all over the world, yet relatively little was known—and this is especially true in America—of the geological relationships, of the mineral parageneses, or of the geographical occurrences, of these classic localities. It was this lack of a comprehensive, up-to-date study of Alpine minerals that provided the impetus for the present work; that, plus a desire on the part of the authors to provide for Switzerland something somewhat equivalent to what Lacroix had done for France in his notable "Minéralogie de la France." That the authors have succeeded brilliantly is apparent to anyone who spends even a short time with these volumes.

The majority of the clefts, it might be explained, are small, flattened, irregularly lens-shaped openings; the length is seldom more than a few meters, and often is less; the height of the opening is commonly measured only in centimeters, although some are a meter or more. A series of clefts frequently exhibits *en échelon* arrangement. The openings are usually transverse to any foliation in the rocks. A feature found in most clefts, with the exception of some in very basic or calcareous rocks, is a band of massive quartz which forms the wall of the cleft against the country rock. The size of this band, as well as of the crystals that project normal from it into the open space of the cleft, is directly proportional to the size, especially the height, of the cleft itself. The minerals that form in a sort of druse on the inside of the quartz layer develop unusually perfect crystal form and include a considerable variety of species, thus permitting exceptionally favorable conditions for paragenetic observations and interpretations. Temperature conditions are estimated by observations on the disappearance of the bubble in fluid inclusions, on the disappearance of color in certain minerals, etc. The age of the clefts is believed to be late-, or post-Oligocene.

Volume I starts with a brief foreword including an historical review by Niggli. Part I (75 pages), by Parker, provides a systematic description of over 200 minerals and a short discussion of the principal rock types. Minerals are arranged as in Niggli's "Lehrbuch." For the less common minerals a paragraph, giving the physical properties and crystal morphology, suffices. More abundant species receive more extended treatment: for example, no less than 16 perspective drawings illustrate the varying crystal habits of anatase. Each mineral is cross-referenced to a locality catalogue. A digest of the major rock types is given: volcanic rocks are few; plutonic rocks are principally granitic, although a wide range is represented; metamorphic rocks are abundant, with gneisses of various types making the majority; sedimentary types are largely calcareous.

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[1] "Zerrkluft" is not readily translated into English, although the term is perhaps sufficiently onomatopoeic to need no direct translation. "Cleft" is used here in preference to "crevice" because it is short, literal, and implies the "tearing apart under tensional stress" which is responsible for the formation of the "clefts."

Part II (nearly 200 pages), also by Parker, presents a detailed description of almost all known Alpine mineral localities. The major subdivisions are geographic: (*A*) the Northern Calcareous Zone; (*B*) the Central Massif; (*C*) the Pennines, and eastern and southern Alps; an Appendix describes occurrences in the Jura. *B* and *C* are subdivided into smaller provinces, and these in turn are subdivided on the basis of different parageneses and these into individual localities. Two large panoramic sketches and a map are folded into the back of this volume and provide an index chart and unequalled "collector's guide" to localities discussed in the text. There is also a page index for minerals and rocks.

Volume II begins with a short foreword by Niggli. Part III (190 pages) is a discussion of parageneses by Koenigsberger. By an amusing simile he stresses the importance of a complete and detailed knowledge of the mineral assemblages; the few choice crystals that find their way into museums, and from which most of us have pictured the Alpine clefts are to be considered, he says, as the "film stars" of the mineral world, and are no more to be taken as a guide to the parageneses than are the goings-on of a Hollywood film star to be taken as a guide to the life of the American people! The striking contribution in this part is the demonstration of the close relationship between the minerals of a cleft and the rock in which it occurs. The 113 paragenetic types are grouped under five country rock types: I, predominantly granitic and quartz-dioritic igneous rocks and orthogneisses of similar composition (without hornblende); II, predominantly silica-rich, hornblende-free metamorphic rocks; III, silica-poor, hornblende-bearing, partially metamorphosed rocks; IV-a, sedimentary rocks, more or less metamorphosed, principally Triassic dolomites or lime-mica schists; IV-b, lime-silicate contact rocks; V, sediments that have suffered little or no metamorphism. This broad grouping is broken down into some two dozen petrographic types for the detailed discussion of the deposits. Here the dependence of cleft mineral assemblages on the country rock becomes increasingly clear; for example, adularia and/or potassium zeolites form where potash has been available in the country rock; albite and/or sodium zeolites where soda has been available; the titanium oxides are relatively abundant where titanium-bearing amphiboles are present, they are scant or absent in clefts in hornblende-free rocks; etc. Koenigsberger is careful to point out that the mineralogical and chemical character of the country rock is not alone sufficient to determine the paragenesis. For example, a younger crevice which cross-cuts an older one, even although both are in the same rock, may have a very different paragenesis. The temperature, the rate of cooling, the pressure, the porosity of the rock, the time of opening of the cleft in relation to the stage of metamorphism—all these play a role in determining the paragenesis. A commonly held misconception is that the clefts all contain a rich variety of mineral species. Actually, many clefts contain little but quartz, or quartz and calcite, or quartz and albite. A rich occurrence requires that the cleft be large and that there be a variety of soluble components in the adjoining country rock. A number of diagrams effectively summarize the many features of the clefts. One diagram, for example, generalizes the temperature sequence for all the cleft minerals in non-carbonate rocks. Here it is shown that relatively few minerals (amianth, kyanite, etc.) began to crystallize above 400°C.; quartz is believed to have begun crystallizing about 300° and continued to around 150°; calcite crystallized in tabular habit around 300°, was resorbed with falling temperatures and then crystallized in rhombohedral habit from 250° to 150°, in scalenohedral habit below 150°; zeolites first appeared a little above 100° and continued to separate to as low as 60° (in the case of laumontite). Another diagram presents data on mineral volumes (quartz is the most abundant, followed by chlorite and adularia); another gives data on crystal dimensions (some quartz crystals are over 100 cm., and some calcite crystals nearly as long); another diagram gives mineral associations; still another relates the parageneses to country rock types.

Part IV (105 pages) by Niggli, concerns the origin of the deposits. He emphasizes again the close chemical relationship between cleft minerals and country rock. Many analyses of both minerals and rocks are given, and equations to represent the transformations are presented. The physical chemistry of the falling temperature sequence of crystallization is discussed. He also stresses the relation of the clefts to Alpine tectonics; the clefts are essentially tensional openings developed in arches formed at the time of the major overthrusts. Immediately after formation of the opening, it was filled with hot water and because of the tectonic conditions affecting the rock, diffusion into a zone around the cleft was furthered. Principally within this zone (although more distant contributions are not excluded) the rock was leached of its more soluble constituents, which with lowering temperatures were redeposited within the cleft to give the typical Alpine parageneses. Only lateral secretion, Niggli feels, can explain all the features of these deposits, and he points to the relative scarcity in the clefts of sulphides and of heavy metals, and the relatively wide-spread distribution of titanium minerals as compared with hydrothermal deposits of magmatic derivation. Taken alone, these items are not sufficient to discount magmatic contributions; but taken in conjunction with the mineral-rock relationships, the case for lateral secretion seems rather convincing.

Part V, by Koenigsberger and Niggli, is a short discussion of the literature on these deposits, with a bibliography of nearly 600 titles, going back as far as the year 1546. Only forty references are found in English-language journals, and of these only three have appeared in American publications!

Illustrations are abundant and excellent. It is regrettable, however, that there is no list or index for the many charts, figures, tables and plates, which last include a number of superb reproductions from photos by F. N. Ashcroft. Transparent overlays for these provide a guide to the geographic and locality details.

When peace comes, Switzerland should again be a Mecca not only for winter sports enthusiasts, glaciologists and structural geologists, but also for mineralogists, crystallographers, and collectors, and possibly for "magmaticists" out "gunning for" this lofty stronghold of the lateral secretionists, for all of whom *Die Mineralien der Schweizeralpen* will be a *vade mecum*. And in the meantime, the book—still available through neutral channels—is a "must" for every mineralogical library.

Ian Campbell

GEM TESTING FOR JEWELLERS by B. W. Anderson. Octavo, 194 pages with 44 figures. Heywood and Co., Ltd., *London*, **1942**.

During the last two decades the number of useful and authoritative texts on precious stones has increased materially. None, however, emphasizes the methods for the testing and identification of gem stones which might well be used by the jeweler and dealer in gems. The author, Mr. B. W. Anderson, has had long experience in this special field, for he is in charge of The Precious Stone Laboratory of the London Chamber of Commerce, Diamond, Pearl, and Precious Stone Section, and Lecturer in Gemmology at the Chelsea Polytechnic, London, S.W.

After indicating how the book may be of service, the various physical properties of minerals and the instruments that are useful in gem testing are described in six chapters, which include the refractometer; double refraction; color, color filters, dichroscope; specific gravity; microscope; and spectroscope. A chapter of sixteen pages is devoted to the detection of synthetic stones, glass imitation, and doublets. Since the microscope plays an important part in the recognition of these and other gem materials, it would be more logical if this chapter followed the description of the microscope rather than precede it. Sixteen chapters are devoted to the identification of important gems and gem materials. An appendix of thirteen pages includes a glossary, alphabetical summary of gem species, description of the crystal systems, a short bibliography, and tables of specific gravities and refractive indices. There is an excellent index.

The book should prove to be very serviceable to those for whom it is specifically designed, namely, jewelers and dealers in gem stones. EDWARD H. KRAUS

X-RAY CRYSTALLOGRAPHY by R. W. James, Senior Lecturer in Physics in the University of Manchester. *London*, Methuen & Co., Ltd., 1930. vii+88 pages, 29 figures. $4\frac{1}{4}'' \times 6\frac{3}{4}''$. Cloth. Price 2*s*.6*d*. Second edition, **1941**. Price 3*s*.

This excellent book, one of a series of small-sized monographs on physical subjects, gives a concise account of the principles involved in the analysis of crystal structures by means of *x*-rays. *X*-ray crystallography is treated as the descendant of geometrical crystallography, bringing proof of the pre-existing theory of the periodic structure of crystals and the underlying framework of space-lattices, point-groups (crystal classes), and space-groups, and giving the means of finding the absolute lengths of the lattice periods and the actual positions of the atoms in the unit cell. A short chapter on the relation of the crystal form to the crystal lattice shows why crystal faces have rational and preferably simple indices. The following chapter on the crystal lattice as a diffraction grating introduces Bragg's rule and gives an account of the earlier methods of observing *x*-ray diffraction. A chapter on crystal symmetry summarizes the classical geometrical theory, shows how lattice centering and the action of glide-planes and screw-axes give systematic spectral omissions, and explains the calculation of the structure amplitude. The following chapter on the measurement and calculation of the intensities of *x*-ray spectra considers theoretical reflection from perfect and mozaic crystals and the effects of primary and secondary extinction; the calculation of f from the distribution of electrons in the atom, and F from the distribution of atoms in the unit cell; the temperature factor; and the determination of atomic parameters by trial and error and with the help of the Fourier series. In conclusion, some simple structural types are described and a short bibliography and index are given.

In the section on external symmetry rotation-reflexion axes are used whereas rotation-inversion axes are now generally preferred. The groupings of the crystal classes into crystal systems avoids the difficulties that arise when the systems are defined by the typical axial relations, but the recognition of a separate trigonal system leads to formal difficulties. Dr. George Tunell has noted that the diagram representing the space-group D_2^5 (Fig. 20) is incorrect.

By a considered choice and economy of words—recalling the style of the author's chief, Sir W. L. Bragg—Mr. James presents a very readable and illuminating introduction to a complex subject. The concise treatment will appeal particularly to research workers who are commencing a study of structural crystallography. The second edition appears to be an unchanged reprint of the first, on better paper.

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NEW MINERAL NAMES

Meta-alunogen

SAMUEL G. GORDON: Results of the Chilean mineralogical expedition of 1938. Part VII. The crystallography of alunogen, meta-alunogen and pickeringite. *Notulae Naturae Acad. Nat. Sciences Philadelphia*, **101**, 9 pp. (1942).

Alunogen occurs with pickeringite in veins in altered andesite near Francisco de Vergara, Chile. Where exposed, the alunogen dehydrates readily to a white, waxy or pearly monoclinic mineral, pseudomorphous after alunogen, and called meta-alunogen. Analysis by William Pitman and Paul Collins gave: Al_2O_3 17.33, SO_3 41.04, H_2O 41.44; sum 99.81%, corresponding to $Al_2(SO_4)_3 \cdot 13\frac{1}{2}\ H_2O$. Optically positive, $\alpha=1.469$, $\beta=1.473$, $\gamma=1.491$, 2E large, obtuse bisectrix perpendicular to cleavage.

Michael Fleischer

Kalsilite

F. A. Bannister and Max H. Hey: Kalsilite, a polymorph of $KAlSiO_4$. *Mineral. Mag.*, **26,** 218–224 (1942).

Name: From the chemical composition.

Chemical Properties: Microchemical analysis by M. H. Hey gave for a fraction of sp. gr. 2.62–2.67; SiO_2 39.6, Al_2O_3 21.3, Fe_2O_3 5.9, MgO 3.7, CaO 5.0, K_2O 20.1, Na_2O 1.6; sum 97.2%. Ignition loss at 800°C. less than 1%. The Fe, Ca and Mg may be due to inclusions of phlogopite or diopside, but the pure mineral contains some iron. Readily attacked by dilute HCl giving gelatinous silica.

Crystallographic Properties: Occurs in irregular grains showing no crystal faces. No cleavage observed. Laue and oscillation photographs show kalsilite to be hexagonal, space group $D_6^6=C6_32$. It differs from kaliophilite and synthetic orthorhombic $KAlSiO_4$ and is not isomorphous with nepheline. The unit cell constants are: $a=5.17$, $c=8.67$ Å., and the unit cell contains 2 $KAlSiO_4$. *X*-ray powder diffraction data are given.

Physical and Optical Properties: Colorless. Sp. gr. $=2.59\pm.03$. Uniaxial, negative, $\omega=1.542$, $\epsilon=1.537\pm.002$.

Occurrence: Occurs as "pegmatitoid segregations" in the rocks from southwest Uganda named mafurite, kalsilite-ugandite and kalsilite-katungite by Holmes. (*Mineral. Mag.* **26,** 197–217 (1942). These are potash-rich ultrabasic lavas containing varying proportions of olivine, melilite, diopsidic augite and leucite. Other minerals associated with kalsilite are phlogopite and a zeolite related to harmotome. Also occurs in mafurite-venanzite rock from Pian di Celle, San Venanzo, Italy (Holmes, *Geological Mag.*, **79,** 225–232 (1942).

M. F.

Shilkinite

G. W. Merkulova: A new mineral—shilkinite. *Mem. Soc. Russe Mineral.*, **68,** No. 4, 559–561 (561 in English) (1939).

Name: For the locality, Shilka River (?).

Chemical Properties: Analyses are given of grayish-green (I) and greenish-white varieties.

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO
I	45.17	tr.	37.03	1.30	tr.	0.04	0.47
II	46.59	tr.	34.50	2.20	0.15	0.05	0.53

	Na_2O	MgO	K_2O	H_2O+	H_2O-	Sum
I	0.47	0.60	8.09	6.31	0.65	100.13
II	0.44	0.88	8.11	5.80	0.71	99.96

These give the formula $K_2O \cdot 4Al_2O_3 \cdot 8SiO_2 \cdot 4H_2O$. Insoluble in acid.

Physical and Optical Properties: Color grayish-green, bluish-green, yellowish-green, sometimes white. Luster silky to dull. Hardness = 3–4. Sp. gr. = 2.795–2.804. Forms fibrous and fan-shaped aggregates. In thin section shows distinct prismatic cleavage and parting normal to it. Optically negative, $\alpha = 1.55$, $\beta = 1.570$, $\gamma = 1.585$, 2V(−) 67°. Dispersion $r < v$, distinct. Pleochroism weak, α=brownish-yellow, β=light yellow, γ=colorless. Elongation positive. Elongated section has parallel extinction.

OCCURRENCE: Occurs in pegmatite dikes of the Bortshovotshny range on the right shore of the Shilka river, eastern Transbaikalia. Associated minerals are orthoclase, albite and smoky quartz. It replaces orthoclase and occurs sometimes as veinlets cutting orthoclase. Sometimes replaces prismatic crystals of some primary mineral which is not preserved.

DISCUSSION: The analyses suggest a relationship to the hydrous mica group (bravaisite, illite).

M. F.

NEW DATA

Skutterudite, Smaltite, Chloanthite, Safflorite

RALPH J. HOLMES: Relationships of the higher arsenides of cobalt, nickel and iron occurring in nature. *Science*, **96**, 90–93 (1942).

This is a preliminary report of *x*-ray studies of natural and synthetic arsenides of cobalt, nickel and iron. The orthorhombic diarsenides rammelsbergite ($NiAs_2$), pararammelsbergite ($NiAs_2$), and loellingite were synthesized. The synthesis of pure $CoAs_2$ was unsuccessful, but natural safflorite and synthetic (Co, Fe) As_2 (Co:Fe ratio not stated) gave patterns similar to that of loellingite. It is suggested that as all analyses of safflorite are high in iron, safflorite should be redefined as a cobaltiferous loellingite (better, cobaltian loellingite—M. F.) and has doubtful merit as an independent species.

The isometric arsenides were previously classified as the diarsenides smaltite ($CoAs_2$), chloanthite ($NiAs_2$) and arsenoferrite ($FeAs_2$), and as the triarsenide skutterudite (Co, Ni, Fe)As_3. The published analyses deviate widely from these formulas. Microscopic examination of many specimens demonstrates that the low and variable arsenic content of the so-called diarsenides can be accounted for in many cases by admixed lower arsenides, such as niccolite and rammelsbergite. *X*-ray patterns of "diarsenides" and triarsenides are identical and have been shown by Oftedal to be compatible only with the formula RAs_3. $CoAs_3$ has been synthesized and gives the skutterudite pattern as does $CoAs_3$ containing variable amounts of Fe and Ni (amounts not stated). $FeAs_3$ and $NiAs_3$ could not be synthesized. It is suggested that the names smaltite, chloanthite and arsenoferrite be dropped, and that the name skutterudite be used to designate $CoAs_3$ and all the other possible minerals of the isomorphous series $CoAs_3$–$NiAs_3$–$FeAs_3$. The terms nickel-skutterudite and iron-skutterudite are suggested for the members of the series rich in nickel and iron, respectively, not for the end members $NiAs_3$ and $FeAs_3$, whose existence is yet to be demonstrated, though the precise limits of substitution of the three metals in the series are yet to be determined.

DISCUSSION: The nomenclature suggested is objectionable for several reasons, and differs from that recently suggested by Peacock (*Univ. Toronto Studies, Geol. Ser. No.* **44**, p. 65, 1940). Study of these minerals is being continued at both laboratories. It seems best, therefore, to postpone any attempt to systematize their nomenclature.

M. F.

Dussertite

DUNCAN MCCONNELL: *X*-ray data on several phosphate minerals: *Am. Jour. Sci.*, **240**, 649–657 (1942).

X-ray study showed that dussertite is a member of the jarosite group. A new analysis of purified type material by F. A. Gonyer gave: As_2O_5 31.23, Fe_2O_3 34.57, BaO 20.93, CaO 0.08, H_2O 9.30, Insol. 4.10; Sum 100.21%. This gives the formula $BaFe_3(AsO_4)_2(OH)_5 \cdot H_2O$.

M. F.

Pseudowavellite

Duncan McConnell, *op. cit.* *X*-ray study shows that pseudowavellite is a member of the alunite group. This requires revision of the formula heretofore given. The new formula $CaAl_3(PO_4)_2(OH)_5 \cdot H_2O$ agrees well with the analysis by Shannon and meets the structural requirements.

M. F.

DISCREDITED MINERALS

Zepharovichite = Wavellite

Duncan McConnell, *op. cit.* Zepharovichite from the type locality, Třenic near Cerhovic, Bohemia, gave the *x*-ray diffraction pattern of wavellite. The name zepharovichite should be dropped.

M. F.

Callainite, Coeruleolactite (?)

Duncan McConnell, *op. cit.* Callainite from Montebras, Creuze, France, was found to be a mixture of wavellite and turquois. Coeruleolactite from East Whiteland Township, Chester Co., Pa., was found to be turquois. These results throw doubt on the validity of these two mineral species, but the type material of neither mineral has been re-examined and the minerals cannot be considered discredited.

M. F.

Arthur P. Honess professor of mineralogy and petrology at Pennsylvania State College and a member of the faculty of that institution for twenty-five years, died December 17, at the age of fifty-five years. From 1937–1940 Professor Honess served on the Council of the Mineralogical Society of America.

A notice has been received of the death of Sir Henry Miers at the age of eighty-four years. He was Waynflete professor of mineralogy at the University of Oxford from 1895 to 1908; principal of the University of London from 1908 to 1915; and vice-chancellor of the University of Manchester and professor of crystallography from 1915 to 1926.